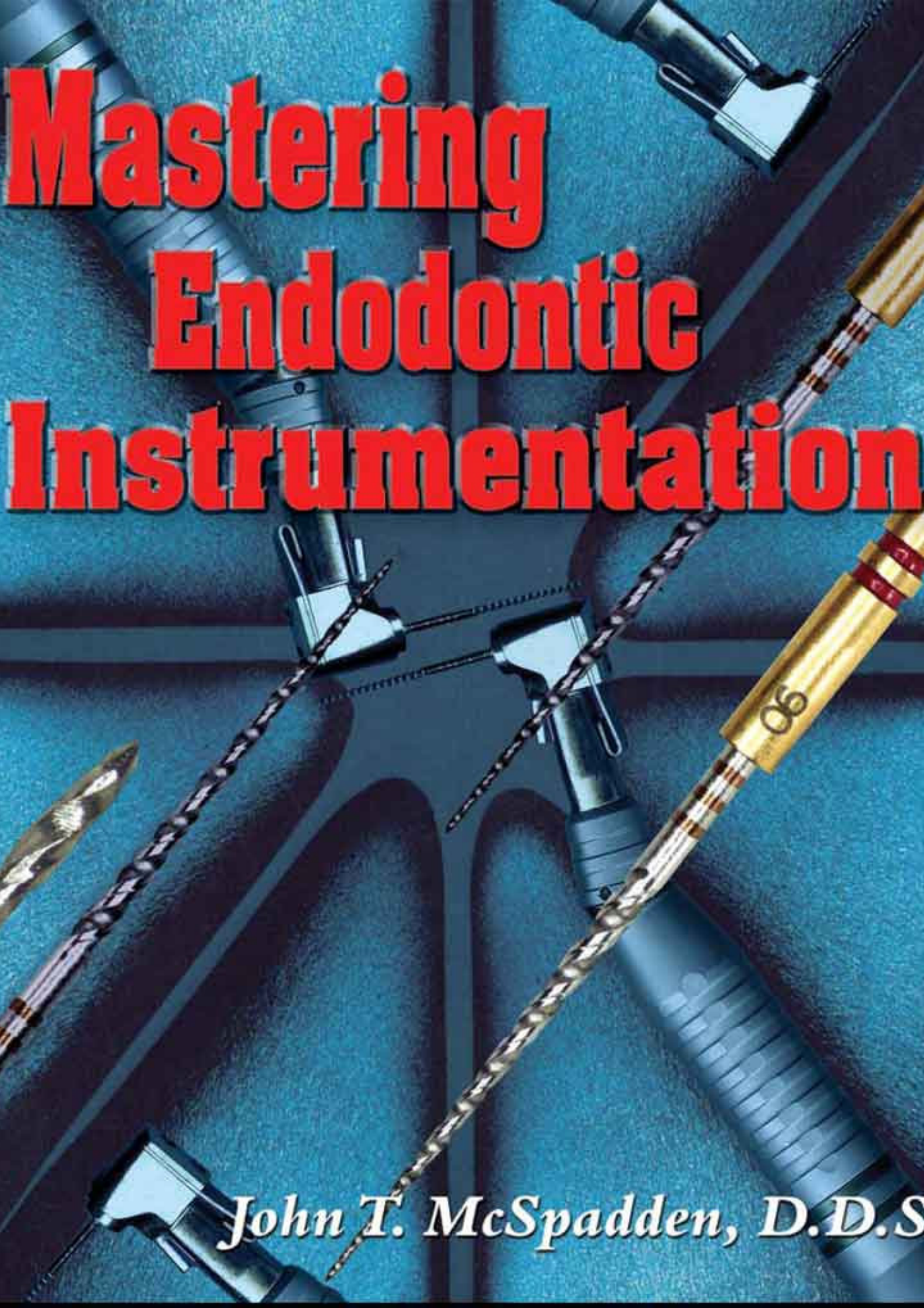


The background of the cover features several endodontic instruments, including handpieces and files, arranged diagonally across a blue, textured surface. The instruments are metallic and have various components like handles, triggers, and shafts. The lighting creates highlights and shadows, emphasizing their three-dimensional form.

Mastering Endodontic Instrumentation

John T. McSpadden, D.D.S.

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Mastering Endodontic Instrumentation

John T. McSpadden, D.D.S.

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Mastering Endodontic Instrumentation

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John T. McSpadden, D.D.S

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Perhaps nothing better typifies the generosity endodontics has been so fortunate to have had in their leaders as their willingness to take a personal interest in the interest of others. I am fortunate to know that first hand. I was the recipient of that generosity when virtually the only reason they had for knowing me was that I was asking them questions. I know of no one so indebted to so many internationally recognized endodontists as I am for having been guided and inspired to pursue endodontic excellence. At the risk of being embarrassed for not listing key individuals responsible for all the important events of my career, there are some that have given particular personal support for my early endeavors. They are: Stephen Schwartz, Barry Korzen, John Ingle, Dudley Glick, Al Frank, Richard Burns, Noah Chivian, Herbert Schilder, Frank Weine, Jeffery Hutter, Al Krakow, Vinio Malagnino, Jean Marie Laurichaise and Dan Even.

I am especially grateful to Dr. Melissa Marchesan from Brazil who spent weeks at my home conducting research for hours on end, day in and day out, and to my son, John Thomas McSpadden, for manning the computerized protocols.

Most of all, I am grateful, as always, to my wife, Jane, for her loving patience and support while it must have seemed to her that I was writing an esoteric non-ending prescription for slumber. My children, Melinda, Matthew, John Thomas and Kathleen, make every endeavor worth while.

Reviews

Once in a great while, an individual has the courage, talent and expertise to provide the profession with a benchmark by which all other studies, anecdotal claims and personal bias must adhere. Dr. John T. McSpadden has provided the dental profession and the specialty of endodontics with such a benchmark....

The text of this book is written for the most part in the first person allowing for personal interpretation of the experimental results based on hard data without being dogmatic. This style acknowledges that there may be other opinions relative to the information put forth in this text but Dr. McSpadden has set the bar high for those who may disagree. The essence of a work such as this is that Dr. McSpadden has dared to establish protocols and scientific methodology on which differences of opinion can be evaluated....

This book should be mandatory reading for all dentists interested in the selection of an instrumentation technique along with an understanding of the safe and effective utilization of the instruments chosen.

Stephen F. Schwartz, DDS, MS

Past Pres. AAE

Vice Pres. ADA

Houston TX

"Mastering Endodontic Instrumentation" is a unique book covering a most important segment of the endodontic curriculum. Dr. McSpadden's book breaks down cleaning and shaping root canal systems into its most basic and scientific components..... a major goal of the author is to help the clinician truly understand why various approaches to cleaning and shaping work rather than limiting teaching to more conventional step-by-step instruction. New and experienced clinicians alike will benefit from understanding why techniques work rather than just how a system is reported to shape canals. Basic rules along with evidence of their validity are presented which apply to all endodontic shaping instruments..... Applying the basic principles presented should help clinicians with an interest in endodontics perform higher quality cases more efficiently.

Van Himel, DDS

Professor and Department Chair

University of Tennessee Health Science Center College of Dentistry

Memphis, Tn

....."Mastering Endodontic Instrumentation" is a primer for anyone wishing to expand their knowledge and understanding of rotary instrumentation. Whether you are someone new to this genre of instrumentation or a seasoned endodontist or general practitioner, this book presents valuable information on how to elevate your cleaning and shaping techniques to a higher level. In addition, this presentation disseminates the most comprehensive approach to understanding the evolution, physics, limitations and underestimated benefits of rotary instrumentation I have ever seen. That makes this text a very important addition to your endodontic library.

Marc Balson, DDS

Past Pres. AAE

Livingston NJ

The book is a masterpiece of Socratic learning; a logical, progressive and systematic examination of how root canal anatomy dictates the selection and use of endodontic instruments. The text offers exhaustive assessments of materials, file systems, handpieces and design features and accompanies them with unsurpassed imagery.... Research was the seminal force behind "Mastering Endodontic Instrumentation.... All the results are devoid of operator subjectivity; thus the content is evidence-based and incontrovertible... Dr. McSpadden poses questions and then answers them and each logical thought progression takes you from one topic to the next as the assessment of all current systems, their strengths and their weaknesses, is defined in the most extraordinary detail.

The scholarship evident will provide both the inexperienced and consummate practitioners with a means to exponentiate their expertise....

In its elegance, lies its simplicity; the cogent and concise scientific explanations for instrumenting complex cases are unprecedented...

...He has written the definitive text for present and future generations to understand and appreciate the enormity of his contributions to the endodontic discipline.

Kenneth S. Serota, DDS, MMSc

Founder, RxROOTS.com

Mississauga ON

.....The high resolution photographs used in the book surpass anything I have seen in the dental literature....

This book should be required reading for every dental student at both the graduate and under graduate levels....

The information delivered in this book is truly evidence- based.

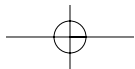
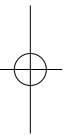
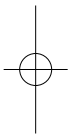
L. Ronald Martin, DDS, MS

Jackson, MS

John T. McSpadden, D.D.S

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Someone once asked, "Which is worse, ignorance or apathy?" The answer was, "I don't know and I don't care." This book is not for them. This book is about developing expertise and employing knowledge for those that aspire to become the best.

Introduction

The two primary goals for root canal instrumentation are:

- 1. To provide a biological environment that is conducive to healing.**
- 2. To provide a canal shape that is conformable to sealing.**

At this stage of endodontic development, common to all instrumentation techniques is the use of endodontic files. Although not universally used, rotary instrumentation is gaining universal interest. The purpose of this book is to provide information gained from extensive research to facilitate the most efficient use of rotary instruments, without the threat of failure, while conforming to the clinician's treatment ideals.

I am convinced the investment in time required for understanding the physics of rotary instrumentation technology can save hundreds of hours, hundreds of mistakes and hundreds of thousands of dollars—benefits

rarely attainable. The greatest benefit, however, of utilizing design concepts is enhancing the quality of treatment while enjoying the practice of excellence.

One should not, however, succumb to a predisposition that concepts resulting in a reduction of time are necessarily a compromise. Just because threading a needle may require multiple attempts and require more time than being successful on the first attempt does not mean that the extra time renders it more worthy than immediate success; regardless of the time invested, the result is a threaded needle.

Ask the question: If every single action you made during instrumentation resulted in the greatest benefit possible in the most efficient manner, how would it change the quality and profile of your practice? Most would agree that the ability to replace repetitious, unnecessary and counterproductive actions, with only the most effective actions, would be true excellence. However, it certainly could

Although a dramatic reduction in time required to accomplish instrumentation may be the consequence of this understanding, it should be emphasized that this is not the result of quickness or ergonomics. Rather, it is due to increased control and the ability to anticipate the optimum approach as well as eliminate the less than optimum, the unnecessary and sometimes counterproductive components of a technique.

Mastering Endodontic Instrumentation

not be done with the information available. Most would also agree that there is no one source dedicated to this kind of information. Currently, accessible information is practically limited to cookbook type instructions with virtually no rationale of rotary instruments and techniques. Instructions for new rotary files are generally comprised of a few concise technique recommendations, making the assumption that these will be adequate to prevent compromising endodontic treatment while attempting to convince the practitioner to employ yet another unique design of instruments. Consequently, endodontists

and an easy technique that could be used as a routine. Many were attracted by claims that techniques, having the fewest instruments, facilitated canal preparation. Most found a functional comfort level quickly, with their initial choices, occasionally added their own modifications, and as experience was acquired, ventured to use other instruments and techniques. Most eventually gravitated toward a level of satisfaction.

Lacking both the benefit of a teacher and any prescribed step-by-step technique, my initial design and use of this new modality for canal preparation, required the continuous

Unaware of the benefits of the extraordinary, the ordinary benefits limited the development of the practice and the practitioner continued to operate with the needless threat of failure and/or the unnecessary consumption of time. This book is for those who want to progress beyond that point.

often needlessly spend most of their chair time preparing root canals with the accompaniment of uncertainty, mediocrity or an arduous attempt at achieving the ideal. Understanding essential information provides the means for expertise. The problem is most will never study information, as it becomes available, to know the difference. Some, however, who are willing to invest the time required for understanding the dynamics of instrumentation will certainly save thousands of hours of chair time, significantly increase their income, and have the satisfaction that they are providing excellence for their patients.

Those who have incorporated rotary instrumentation into their practice understandably looked for a simple system of files

attempt to thoroughly understand the physics of rotary instrumentation. The “doing” required careful visualization of all the consequences of actions before they were performed. Ironically this exercise proved uniquely advantageous over the regimented procedures most have had to follow and soon I developed the understanding for instrumenting complicated anatomies with relative ease. The expeditious accomplishment of instrumentation caused inexplicable guilt, but challenged my ingrained notion so common to dentists, that speed was a compromise. That notion was replaced with the realization that expertise and efficiency are synonymous and both are relative to the level of understanding.

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Unfortunately, I attempted to convey instructions by teaching conventional step-by-step techniques rather than the understanding I had acquired and that clinicians could have easily learned. I thought, and was told, that dentists only wanted to know how rather than why. The reality, however, is as the introduction of new products increases and voices of advocates confuse those choices, coupled with the fact that products become obsolete before they can be thoroughly evaluated, the need for understanding the principles of all products, especially rotary instrumentation, becomes apparent. As scientific evaluations encompass only a small portion of the total functionality of instrumentation, and as more instruments are described only in terms of their unique features, the need for consolidation of information becomes indispensable for the endodontist who strives to exercise judgments and skills beyond those afforded by the set of instructions as a beginner or the satisfaction level of the consummate user. A basic understanding of the scientific principles of instrumentation needs to be the foundation of expertise rather than instructions or recommendations that seem to lead to multiple and temporary conclusions.

With understanding, there is no need to rely on time consuming and costly trial and error experience. It is easy to forget that it requires ten years to have ten years of experience. Neither is there a need to rely on the ability to decipher conflicting explanations of noted authorities. With understanding, improvements in the quality of care occur more quickly and consistently. The need is to make understanding accessible. The longer

we continue practicing without appreciating the rudimentary principles and characteristics of instrumentation, the greater the gap between newer technologies and understanding becomes and the less we use the full potential technology has to offer. The purpose of this presentation is to provide and consolidate the principles necessary for understanding the design of instruments and for developing the rationale necessary to formulate and use present and future instruments to their greatest benefit in relation to the canal anatomy.

As one examines the principles of rotary instrumentation, the cookbook type techniques that were once beneficial for initiating the use of rotary files in one's practice become overly simplistic. The ability to differentiate between the attributes and limitations of instruments and techniques become apparent. Rather than espousing a popular technique, understanding consigns only the appropriate technique that changes for every anatomy and case history. It is important not to confuse the characteristics of instruments with the techniques with which they have become associated. The advantages and disadvantages of techniques do not necessarily pertain to the instruments used. It is also important to understand that desired canal shapes can be prepared with virtually any series of instruments, but it is the risks and efficiency that varies from one instrument to another.

With understanding, approaches to different cases become too diverse to fall within any particular category other than canal anatomy. Even though the choices of instruments and techniques can become more numerous and complex for cleaning and shaping canals, the

solutions become less complicated and expedient. As one broadens the scope of understanding, skill is enhanced in a scientific manner and success becomes more predictable. The art of endodontics becomes the science of endodontics and expertise becomes the nature of the operator.

Since I receive royalties from several of the instruments discussed in this book, I am extremely sensitive to the fact that some might view any evaluations under my direction to be skewed by commercial interests. I can only say that the motivation that prompted me to seek ways to improve the quality of treatment, ways that ultimately developed virtually all innovations in our profession, is the same motivation that has led me to advance concepts for understanding. Even though every effort has been made to make any findings of testing be the result of following solid scientific protocol that can be easily duplicated, and all testing has been conducted by only using mechanical devices that operate independent of operator variables or subjectivity, this book does not pretend to be an authoritative treatise to validate or invalidate the claims for instruments or techniques. Rather, the results of testing are presented as tools to promote understanding, investigation and development. As understanding is developed, any commercial influence of these or any other testing results should become apparent regardless of the source.

While reading this book, you may notice that numerous popular recommendations for using rotary instrumentation will be challenged and exposed as intuitive concepts. One primary purpose of this book is to instill a sense of curiosity for the reasons

of any concept. In fact, this book is a result of other people's curiosity and is organized by asking questions that have at one time or another have been asked of me. The answers are transcripts of those communications or excerpts from lectures and are in a conversational mode for that reason. Addressing these questions is an exercise in determining which procedures enable the dentist to operate with scientific predictability for success. You may be interested to know that some of the following popular concepts are more intuitive, but are counter to scientific evidence:

- 1. Specific speeds of rotation should not be exceeded.**
- 2. Complicated curvatures require slower speeds.**
- 3. Use one continuous motion of file insertion until resistance is met.**
- 4. Routinely follow the use of an instrument with another instrument having the same taper with a smaller tip size.**
- 5. Routinely establish straight-line access.**
- 6. Routinely carry a .04 or even a .06 taper file to working length.**
- 7. A crown-down approach is always preferable to a step-back approach.**
- 8. One millimeter of file advancement into the canal only results in one millimeter of additional engagement.**

These and other concepts are often followed without question. The best use of this book is to use the questions as frameworks for examination. Although research on endodontic instruments cannot result in absolutes, understanding the results of

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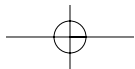
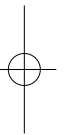
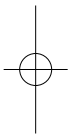
research will provide significant predictability to be used as a guide for formulating techniques. You will note that it is only after a thorough examination of existing instrumentation concepts, in the context of one of the most extensive research projects ever undertaken, that any parameters are recommended for using instruments currently available and for designing prototype instruments for the future. Following those or any parameters should be consistent with your understanding. Any inconsistency may mean either a lack of

understanding, or hopefully, and more importantly, may mean that you have contributed in formulating an advanced concept for a new instrument or technique.

The hope for those reading this book is that they will use the information presented to visualize the actions of existing and future endodontic files and be able to coordinate their characteristics with canal anatomies. The aspiration is to help in attaining expertise. The consequence would be advancing the field of endodontics.



In 1977, Dr. McSpadden was exercising innovation. He was using mechanical instrumentation, the Dynatrac system, and mechanical obturation, the McSpadden Compactor System, both of which he invented. At that early date, he was routinely using the microscope for all practice procedures.



Mastering Instrumentation

The next level of development of rotary instruments is continuously being introduced. Design concepts for various new instruments are important departures from previous designs. To fully comprehend the significance of design principles for advanced developments, it is necessary to determine the considerations by which all rotary endodontic files should be used and evaluated, then assess any new development in that context. This presentation offers those considerations and reviews the evolution of rotary instruments (assessing their advantages and limitations). Within this paradigm will be an understanding of design concepts that enables the practitioner to maximize endodontic skills for any technique available today and to most effectively use and evaluate advancements as they become available in the future. Armed with this knowledge, the practitioner gains independence from advocacy claims and the need for trial and error experience. More importantly, a more rational approach will be offered in providing expertise for treating their patients.

Section I: Mastering the Concepts

With the introduction of nickel titanium, mechanical root canal preparation has quickly become a widely accepted modality in endodontics. The enhanced preparation results and reduced preparation time of rotary nickel titanium files have prompted the rapid adoption of rotary instrumentation. Yet, in spite of added advantages and excellent canal cleaning and shaping ability, a lack of information has caused the formulation of techniques that limited the comprehensive benefits of rotary instrumentation. Even though instrumented canals may result in ideal appearances, information for accomplishing ideal instrumentation has not kept pace with the enhanced opportunities for efficiency, expertise, or the reduction of risks.

Particular canal shapes are often illustrated as being characteristic for certain file brands,

however, canal shapes are more dependent on the file dimensions, the sequence the files are used and the depths to which they are carried into the canal. Although a desired canal shape can be achieved with virtually all brands of rotary nickel titanium files, various techniques have been proposed to achieve this shape. Too often the designs of these techniques are determined by marketing where product promotion prevails over science. Consequently, the practitioner often experiences complications while conscientiously following instructions that disregard the complexities of anatomy.

Understanding the ramifications of file and technique design relative to canal anatomy enables the dentist to consistently achieve the most expeditious and excellent treatment with the least risks. This is not a

new concept. Frank Weine described as early as 1975 in the *Journal of Endodontics* (Weine, F. S.; The effect of preparation procedures on original canal shape and on foramen shape. *Journal of Endodontics* 1:8 August 1975.), a technique for modifying files in order to prevent transporting curved canals. He advocated using a diamond-surfaced fingernail file to remove the blades on one side of an endodontic file that would reciprocate against the outer canal wall between a curvature and apex to avoid zipping the canal, a design known today as the safe-sided file.

Often, techniques are designed to avoid a failure that has been experienced in one particular procedure, even though the application could be beneficial in other circumstances. For example, we are often instructed by some advocates never to rotate a file more than 350 rpm, yet in many circumstances 1200 rpm can be more than four times as effective with less threat of complications, and slowing the rotations can actually increase the threat. Consequently, without having the information needed to understand how to utilize the advantages while limiting the threat of failure, the practitioner frequently places limits on rotary instrumentation prematurely before expertise

and its most significant benefits are ever realized. The science for integrating anatomical canal complexities with instrumentation efficiency and effectiveness is the most often ignored technique consideration. Wasted time and needless difficulties are most often the consequences.

By and large, basic rudimentary physics of root canal instrumentation has been an elusive subject during the last century, denying even the endodontist the understanding necessary to fully attain their potential expertise in

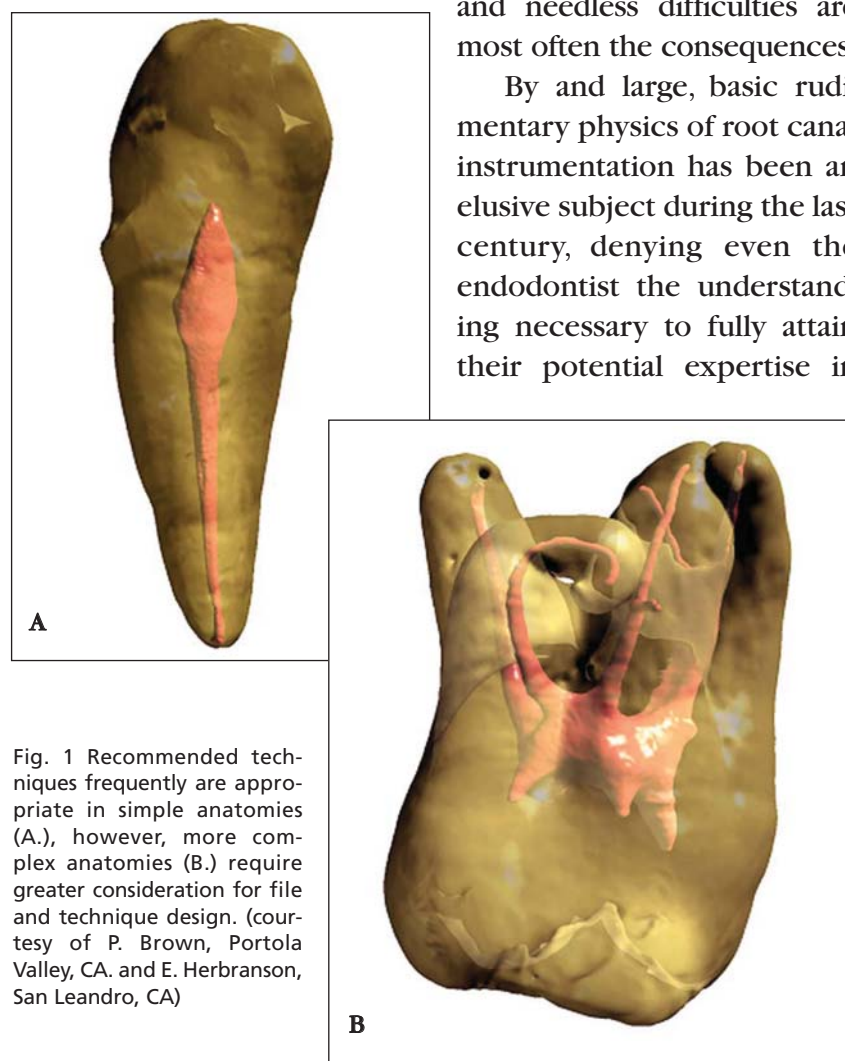


Fig. 1 Recommended techniques frequently are appropriate in simple anatomies (A.), however, more complex anatomies (B.) require greater consideration for file and technique design. (courtesy of P. Brown, Portola Valley, CA. and E. Herbranson, San Leandro, CA)

performing the task that often requires the major portion of their time: root canal preparation. Rotary instrumentation is certainly not a new concept; it was introduced in the late 19th century, as were the rubber dam, rubber dam clamps, and even solid core carriers for gutta percha which

John T. McSpadden, D.D.S

were introduced at the beginning of the 20th century.

The first manual and mechanical rotary files were formed from straight piano wire that had flats ground on its sides and twisted to result in the configuration of files still used today. Files were first mass-produced by Kerr Manufacturing Co. in the very early 1900's, hence the name K-type file or K-type reamer. Although the term file is commonly used generically to describe all ground or twisted endodontic instruments, more specifically the term file is used to describe an instrument used primarily during insertion and withdrawal motions for enlarging the root canal, whereas a reamer is used primarily during rotation. K-type files and reamers were both originally manufactured by the same process. Three or four equilateral flat surfaces were ground at increasing

depths on the sides of wire to form a tapered pyramidal shape that was stabilized on one end and rotated on its distal end to form the spiraled instrument. The number of sides and spirals determined if the instrument was best suited for filing or reaming. Generally, a three-sided configuration, with fewer spirals, was used for reaming or rotation; a three- or four-sided configuration with more spirals was used for filing or insertion and withdrawing. Even though the twisting method of file manufacturing has generally been considered an outdated means of fabricating files and has been replaced by computerized grinding processes for NiTi rotary files, new advances for manipulating shape memory alloys may offer economic and physical property advantages for reconsidering the twisting method of manufacturing for the future.

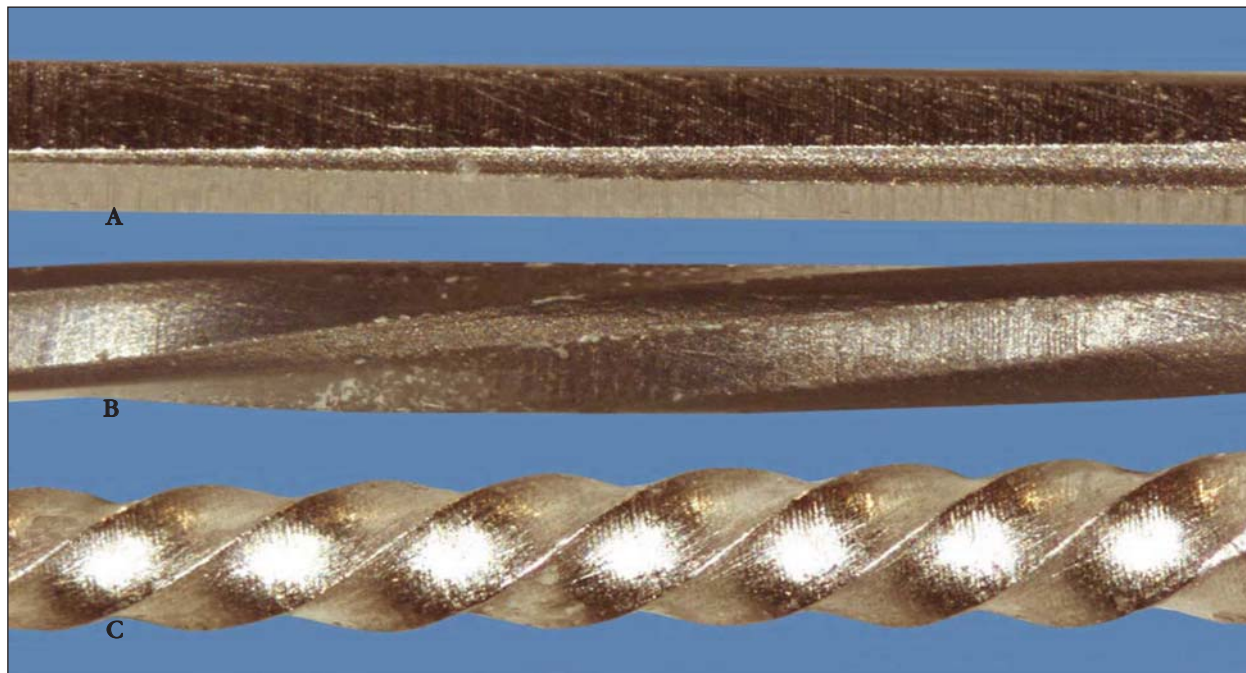


Fig. 2 A. A tapered pyramidal wire is used as a blank for forming a file.
 B. Each end of the blank is stabilized and one end is rotated to twist a spiraled shape on the file's working surface.
 C. Multiple rotations result in the familiar spiraled shape of the endodontic file.

Mastering Endodontic Instrumentation

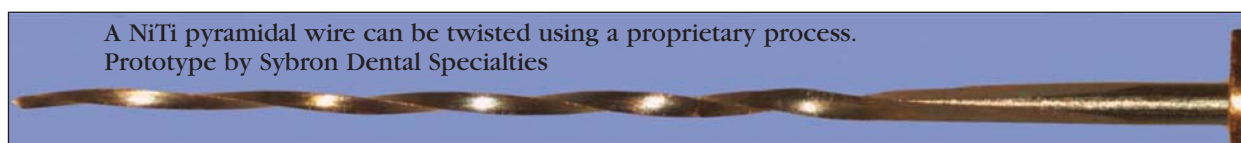


Fig. 3

Dating from the late 19th century, the earliest endodontic instruments used for extirpating the pulp and enlarging the canal were broaches or rasps. Still used today, these instruments are manufactured by hacking a round tapered wire with a blade device to form sharp barbs that project out from its side to form cutting or snagging surfaces. Although mostly used to engage and remove soft tissue from the canal as manual instruments, these historic broach type instruments have the potential for becoming effective rotary instruments. The evolutionary development for endodontic instruments seems to have some cyclic peculiarities and is far from over. Even the tapered pyramidal design originally used as blanks as described above is now being used as rotary NiTi files.



Fig. 4

1. What are the terms I need to know when comparing the physical properties of files?

The success of using instruments while preventing failure depends on how the material, design and technique relate to the forces exerted on the instruments. To fully understand how the file reacts to applied forces, terms have been defined to quantify the actions and reactions to these forces. Common terms related to forces exerted on files have the following definitions:

1. **Stress**—The deforming force measured across a given area.
2. **Stress concentration point**—An abrupt change in the geometric shape of a file, such as a notch, will result in a higher stress at that point than along the sur-

face of the file where the shape is more continuous.

3. **Strain**—The amount of deformation a file undergoes.
4. **Elastic limit**—A set quantity which represents the maximal strain, which, when applied to a file, allows the file to return to its original dimensions. The residual internal forces after strain are removed and return to zero.
5. **Elastic deformation**—The reversible deformation that does not exceed the elastic limit.
6. **Shape memory**—The elastic limit is substantially higher than is typical of conventional metals.
7. **Plastic deformation**—Permanent bond displacement caused by exceeding the elastic limit.
8. **Plastic limit**—The point at which the plastic deformed file breaks.

2. Why Nickel-Titanium?

Manual stainless steel files provide excellent manipulation control and sharp, long-lasting cutting surfaces. However, due to the inherent limited flexibility of stainless steel, preparation of curved canals is often a problem for manual files, and the mechanical use with conventional designs and grades of stainless steel poses the likely threat of file breakage or canal transportation.

The significant advantage of a file made of a nickel titanium alloy is its unique ability to negotiate curvatures during continuous rotation without undergoing the permanent plastic deformation or failure that traditional stainless steel files would incur. The first series of comparative tests demonstrating the potential advantages of endodontic files made of nickel titanium over stainless steel were conducted by Drs. Walia, Gerstein and Bryant. The results of the tests were published in an article entitled "An Initial Investigation of the Bending and the Torsional Properties of Nitinol Root Canal Files," (*Journal of Endodontics*, Volume 14, No.7, July 1988, pages 346-351). In 1991, the first commercial nickel titanium manual and rotary files were introduced by NT Co. In 1994, NT Co. also introduced the first series of nickel titanium rotary files having multiple non-conventional tapers: the McXIM Series, which had six graduating tapers ranging from the conventional 0.02 taper to a 0.05 taper file in order to reduce stress by limiting the file's engagement during the serial enlargement of rotary instrumentation. Based upon the initial success and recognized advantages, the use of nickel titanium rotary files has proliferated and become

widely accepted by the profession.

Nickel titanium is termed an exotic metal because it does not conform to the normal rules of metallurgy. As a super-elastic metal, the application of stress does not result in the usual proportional strain other metals undergo. When stress is initially applied to nickel titanium the result is proportional strain. However, the strain remains essentially the same as the application of additional stress reaches a specific level forming what is termed *loading plateau* during which the strain remains essentially constant as the stress is applied. Eventually, of course, excessive stress causes the file to fail.

This unusual property of changing from an anticipated response to an unanticipated response is the result of undergoing a *molecular crystalline phase transformation*. NiTi can have three different forms: martensite, stress-induced martensite (superelastic), and austenite. When the material is in its martensite form, it is relatively soft and can be easily deformed. Superelastic NiTi is highly elastic, while austenite NiTi is non-elastic and hard. External stresses transform the austenitic crystalline form of nickel titanium into the stress-induced martensitic crystalline structure that can accommodate greater stress without increasing the strain. Due to its unique crystalline structure, a nickel titanium file has shape memory or the ability to return to its original shape after being deformed. Simply restated, nickel titanium alloys were the first, and are currently the only readily available economically feasible materials that have the flexibility and toughness necessary for routine use as effective rotary endodontic files in curved canals. Other alternative materials are being investigated for the same purpose.

Mastering Endodontic Instrumentation

Comparison of Properties of NiTi and Conventional Stainless Steel

Property	NiTi	Stainless Steel
Recovered Elongation	8%	0.8%
Biocompatibility	Excellent	Fair
Effective Modulus	approx. 48 GigaPascal	193 GigaPascal
Torqueability	Excellent	Poor
Density	6.45 g/cm ³	8.03 g/cm ³
Magnetic	No	Yes
Ultimate Tensile Strength	approx. 1,240 MegaPascal	approx. 760 MegaPascal
Coefficient Thermal Expansion	6.6 to 11.0 x 10 ⁻⁶ cm/cm/deg.C	17 .3 x 10 ⁻⁶ cm/cm/deg.C
Resistivity	80 to 100 micro-ohm*cm	72 micro-ohm*cm

Table 5 (Breme HJ & Biehl V (1998) Metallic biomaterials. In: Black J & Hastings G (eds) Handbook of biomaterial properties, Chapman & Hall, London, p 135-213.)

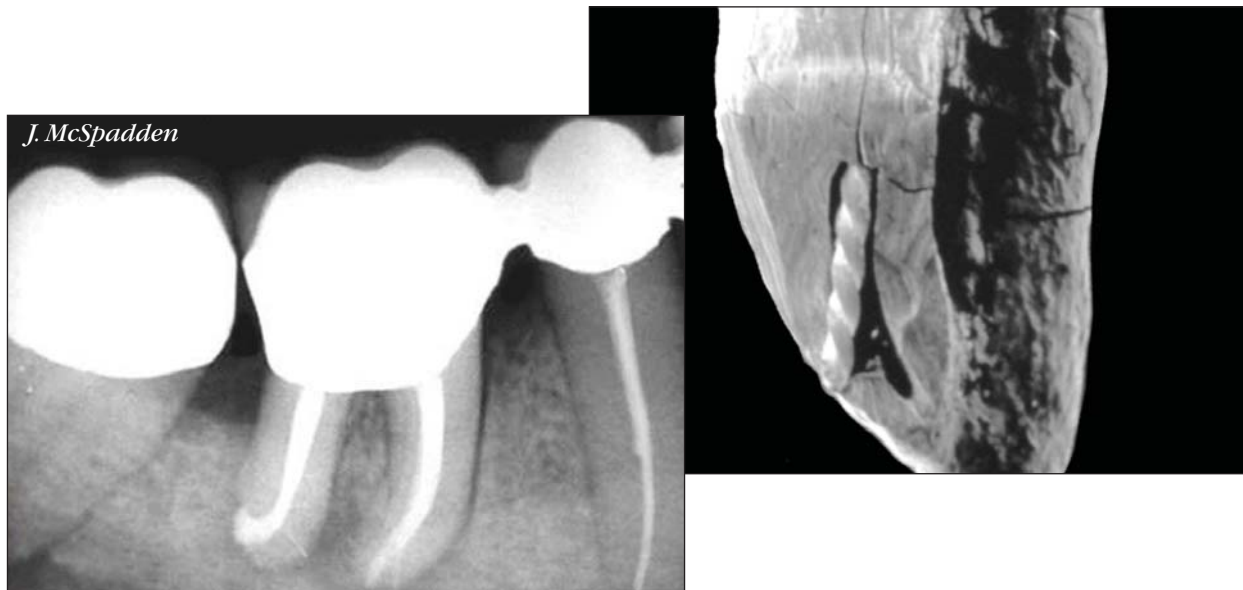


Fig. 6 Although stainless steel files could negotiate abrupt apical curvatures (left image), canal transportation could easily occur due to the file's lack of flexibility. Note the transportation that occurred in the apical curvature that occurred during instrumentation with stainless steel files. "Zippering" the apical foramen can be a consequence of file inflexibility.

3. Are nickel titanium files always advantageous over files of stainless steel during rotary instrumentation?

The function and physical property requirements of endodontic files are extremely important and need to be matched to manufacturing methods. Metallurgy of the specific material should be understood to achieve optimum properties for the application.

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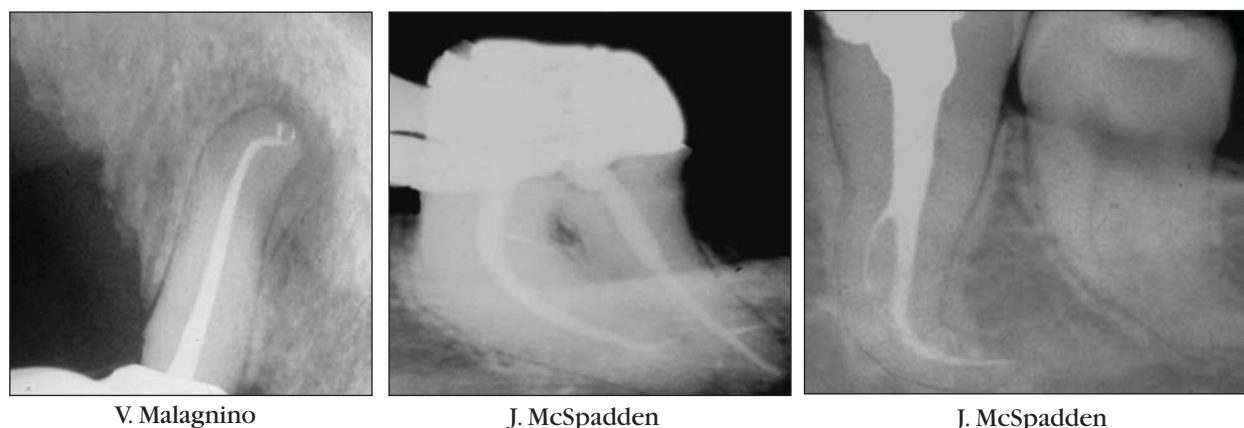


Fig. 7 Early cases for using nickel titanium rotary files demonstrated the ability of preparing canal curvatures while maintaining the central axis of the canals.

Stainless steels are a good case in point. Over 100 alloys, of which many have only recently been introduced, are included under the banner of stainless steel. Endodontics, unfortunately, has been lacking in its investigation of alloy selection and when we compare NiTi files with stainless steel files, we do so within the narrow framework of older stainless steel alloys that have been used for files. Comparisons between the two metals may change significantly in the future.

If all canals were straight, conventional stainless steel files would have results as good as, or better, than nickel titanium. Work hardened stainless steel files have more torsion strength and are able to maintain sharp edges longer. Of course, few canals are entirely straight and rarely can degree, radius, and direction of curvature be determined prior to treatment. The minor curvatures of most canal anatomies can cause excessive stresses on conventional stainless steel files and result in unwanted canal transportation or file failure. Nevertheless, the introduction of nickel titanium files seemed to ignore the fact that nickel titanium offers no advantage

for files having large diameters and tapers that lack any appreciable flexibility. Accordingly, these instruments have become an unnecessary expense, only because these larger files were a part of a series of instruments. The advantage of stainless steel rotary files of larger diameters and tapers to compliment the use of nickel titanium files is now recognized by many that have become familiar with the attributes and limitations of nickel titanium. Stainless steel rotary files are being introduced for use in lieu of nickel titanium files in larger sizes and tapers that lack the flexibility. More advanced design developments that reduce file stresses and modifications in the molecular structure of stainless steel are continuously causing reconsideration of stainless steel as a viable NiTi alternative.

4. Are there other alloys that offer advantages as rotary files?

Other alloys have been developed that are suitable for rotary files and might have properties that are advantageous over those of nickel titanium. One problem is economics.

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In order to be feasible, any other alloy usually must have applications in addition to rotary files that can help offset the cost of production. Otherwise the costs can be prohibitive. Another problem is ignorance. New materials and methods for altering the characteristics of existing materials are developing at such a rapid pace that our awareness simply does not keep up.

One alloy having considerable potential and economic feasibility is a nickel titanium niobium alloy having a substantially higher *loading plateau*, making it tougher than either stainless steel or nickel titanium. It has sharper, more durable cutting edges, and can

be more resistance to breakage. Somewhat stiffer than the conventional NiTi alloys, but more flexible than stainless steel, it is particularly advantageous for rotary activation of smaller files. The flexibility is sufficient to negotiate acute curvatures with minimum canal transportation, yet stiff enough to withstand the pressure desirable to feed it into small canals.

Other titanium alloys contain molybdenum and zirconium to increase stability, workability, or corrosion resistance. Only time will tell if the economic feasibility of these and other alloys will eventually provide a better endodontic rotary file.

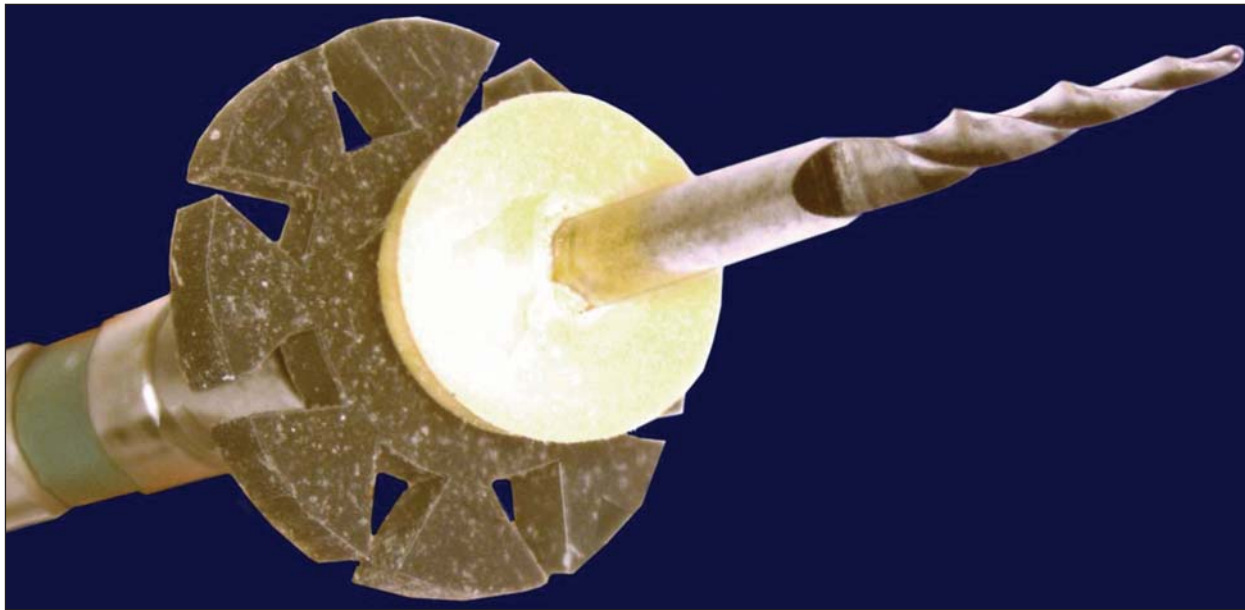


Fig. 8 The FKG stainless steel rotary files are examples of rotary files available in sizes that NiTi files would lack any appreciable flexibility or advantage.

5. Why Rotary Instrumentation?

One benefit of mechanical rotation is the enhanced ability to collect and remove debris from the canal system. Hand instrumentation can push debris laterally into the intricacies of the canal anatomy or even apically through the canal foramen when using techniques that commonly include insertions of files without rotation or rotations of files in a counter-clockwise direction. In contrast, continuous clockwise rotation will convey debris only in a coronal direction from the canal ramifications and apical foramen.

Mechanical rotation provides a more constant 360-degree engagement of the file tip in the canal that forces it to follow the canal and results in better control for maintaining the central axis of the canal, reducing the incidence of ledging or perforating. The flexibility for following the canal allows us to be more conservative in preserving tooth structure while effectively cleaning and shaping the canal. The most obvious benefit for continuous rotation is the reduction in the time required for instrumenting the canal. The fact that a file, constantly rotating from 200 to 2,000 rpm, produces results more rapidly than hand instrumentation that has significantly slower and intermittent rotations, should come as no surprise.

6. Why do we need to know anything about instrument design?

Although radiographs portraying desired canal shapes are often used to illustrate the capabilities of a particular type of file, the desired canal shape can be attained with virtually any set of files provided they are used properly. How efficiently the shape can be

attained is another matter. The capabilities of files made of the same material are entirely dependent on design and can mean success or failure. No one aspect of file design is indicative of the file's overall usefulness. Optimizing one design feature can compromise another benefit. Considerations for design effectiveness include the following: cutting ability, operational fatigue, stress concentration points, operational torque, torque at breakage, flexibility, screwing-in forces, ability to maintain the central axis of the canal, and tip mechanics. Successes of file design and, to a considerable extent, clinical success are determined by how efficiently these considerations address various canal anatomies.

Limitations of the initial nickel titanium file designs were largely due to an attempt to adapt the easily manufactured old hand file designs and technique concepts to these new rotary instruments. These old designs applied to a new modality comprised the first generation of NiTi rotary instrumentation. A second generation of designs, now particularly patterned for rotary instrumentation, is being introduced that can substantially advance treatment results. **In using any file design, understanding the rudimentary physics involved in its use is imperative for the practitioner to take full advantage of its benefits. Recognition of instrument features that improve usefulness or pose possible risks must also be achieved.** This need is especially important in employing a new file design. Regardless of the design and technique, there are certain considerations that provide the understanding for using rotary instrumentation to its fullest advantage. The practitioner must remember that although any new introduction of rotary files

can represent significant improvements, some designs without merit will continue to be introduced for marketing purposes and advocated by clinicians who lack the complete comprehension for the ramifications of use. Any significant treatment advancement will ultimately be predicated on each individual practitioner's understanding of design function. **The ultimate goal for anyone using rotary instrumentation is not only to be able to recognize that pivotal instant just before complications occur, but to recognize the most appropriate approach for achieving solutions. That goal can only be accomplished by thoroughly understanding the function of design.**

7. Is an appropriate technique important?

Canal anatomy, file design and file dimensions dictate the appropriate use of an instrument.

Often techniques for particular files are the result of subjective concepts recommended for the sake of simplicity. The capabilities of the files then become confused with the capabilities of the inappropriately recommended technique with which they have become associated. **How well a file performs, while following a specific technique, should not be the measure of the effectiveness of a file; rather, how well the capabilities of a file can address the requirements of the canal anatomy should be the measure of its usefulness.** Since canal anatomies vary, techniques to effectively clean and enlarge the canal may include modifications and may include different type instruments. Instrumentations involving more than one type instrument or technique are known as hybrid techniques.

8. What are the components of a file?

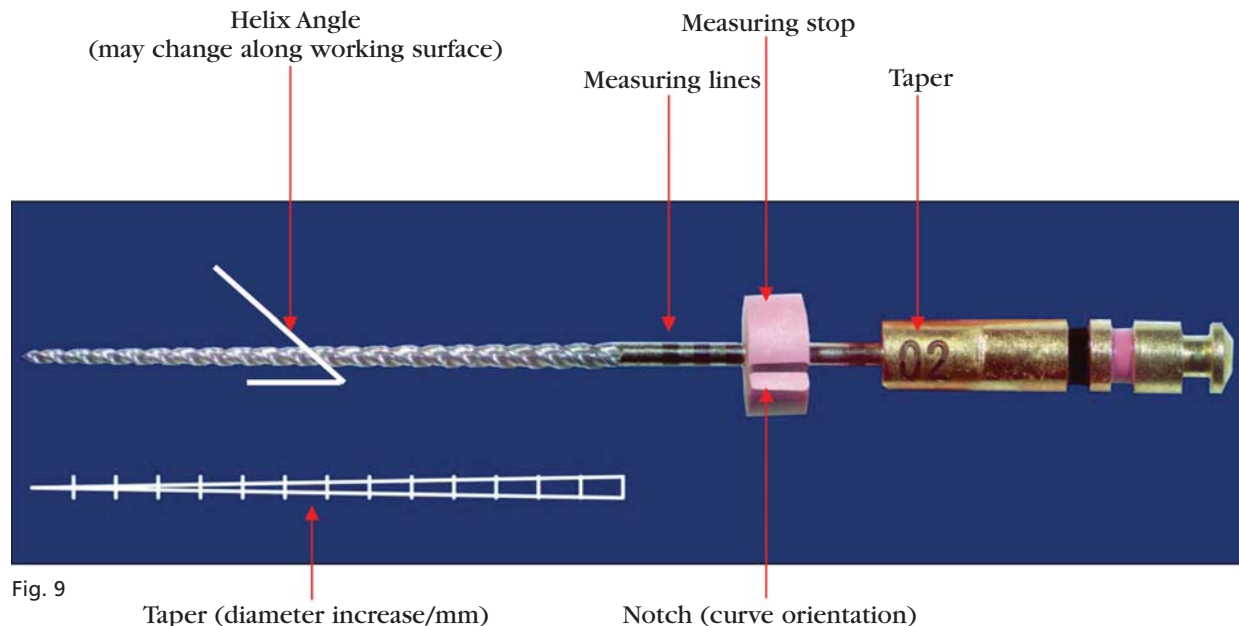


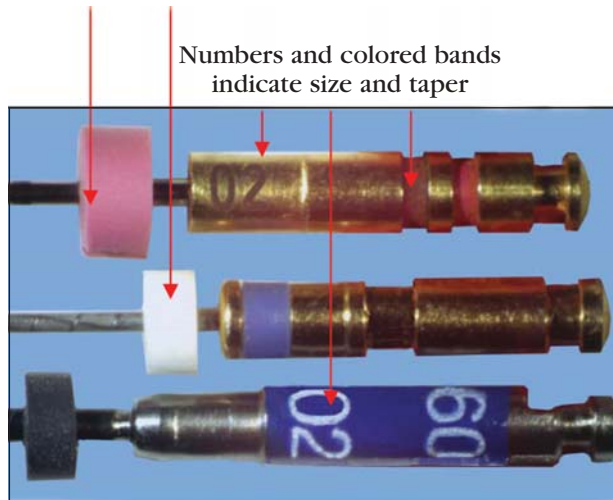
Fig. 9

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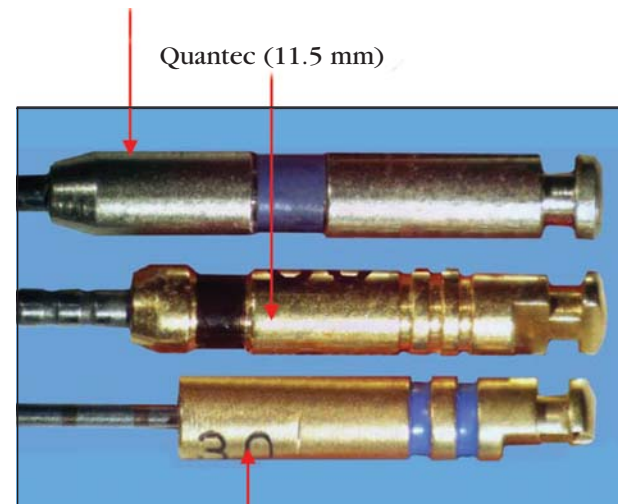
The *taper* is usually expressed as the amount the file diameter increases each millimeter along its working surface from the tip toward the file handle. For example, a size 25 file with a .02 taper would have a .27 mm diameter 1 mm from the tip, a .29 mm diameter 2 mm from the tip, and a .31 mm diameter

3 mm from the tip. Some manufacturers express the taper in terms of percentage in which case the .02 taper becomes a 2% taper. Historically, as an ISO standard, a file was fluted and tapered at 2% for 16 mm, but now files incorporate a wide variation of lengths and tapers of working surface.

Stops may indicate size or taper

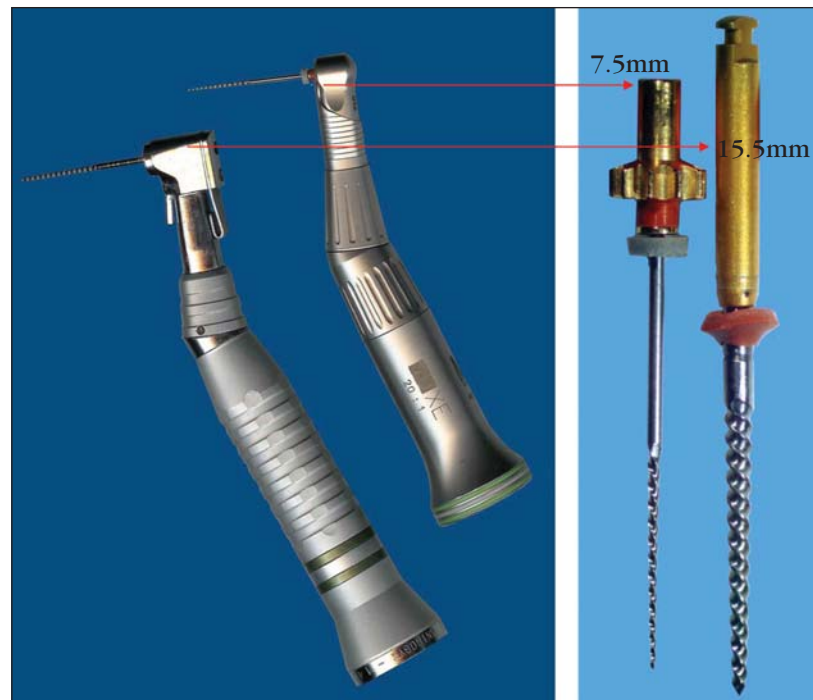


Profile GT (13 mm)



K-3 Access handles can provide greater working and prevent undue stress caused file distortion outside the canal.

Fig. 11 **MicroMega** has used the unique approach of combining the pinion gear of the hand-piece and the handle of the file to increase access. The result is a handle that is 7.25 mm in length or less than one half the length of a standard handle.

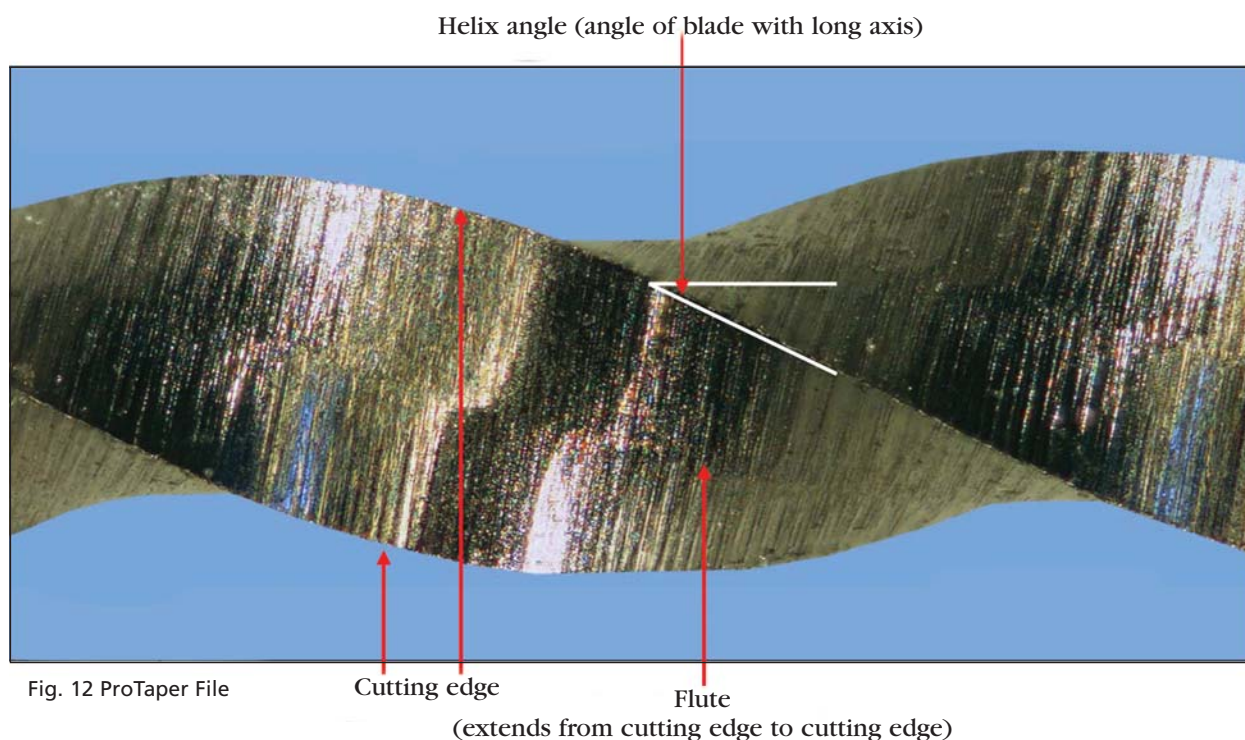


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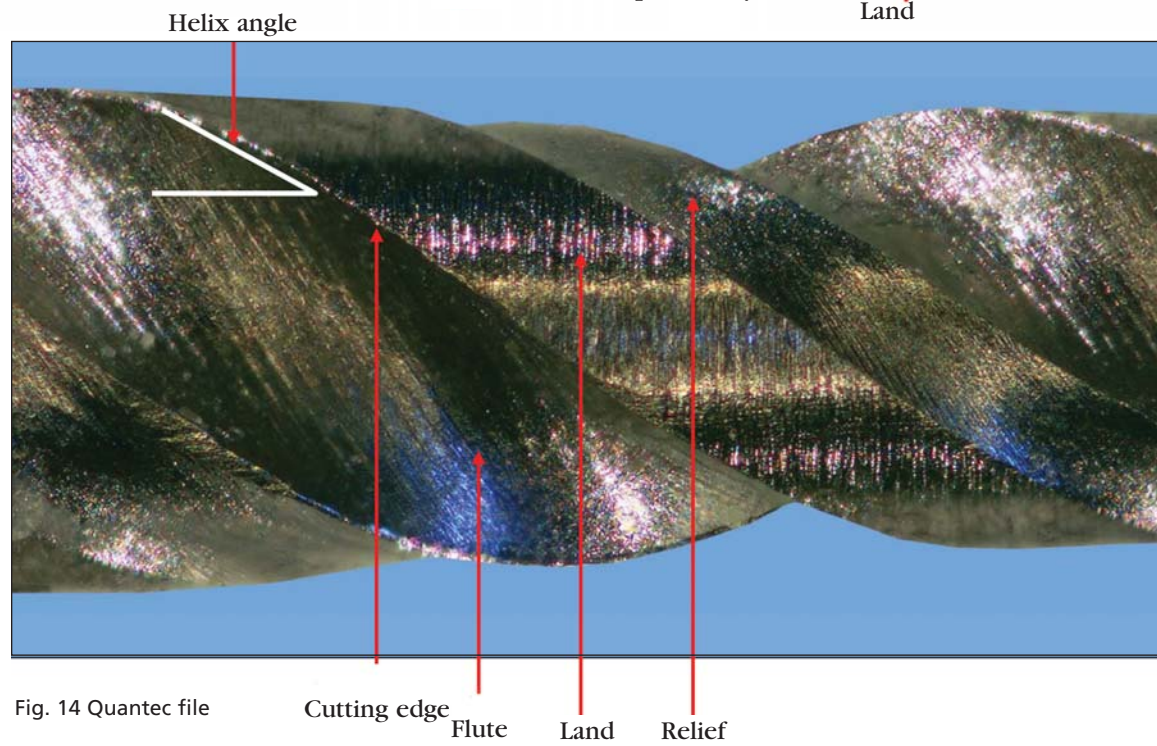
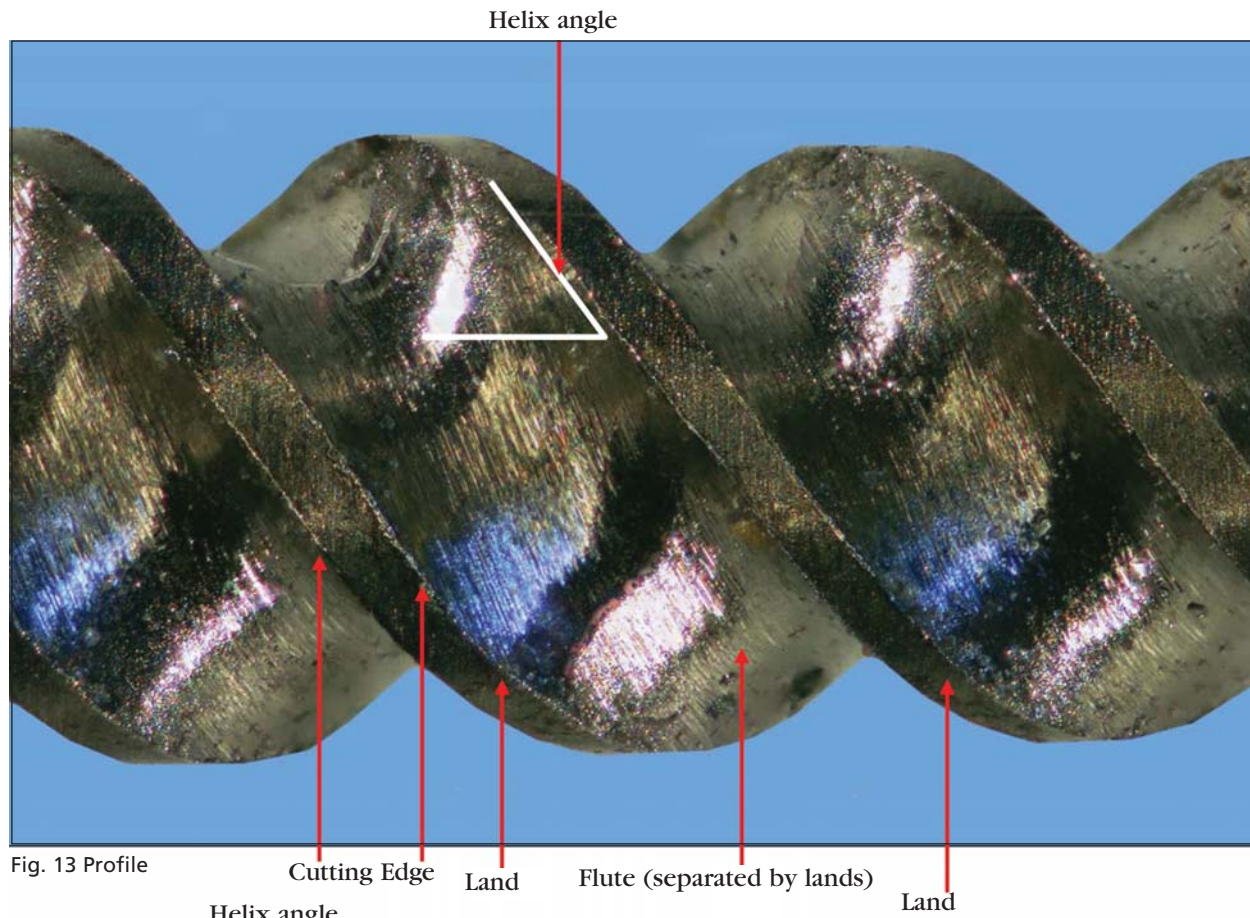
Standardized dimensions played an important role at the time they were instituted for providing the needed consistency for hand instruments, but were soon seen as limitations for rotary instrumentation. As different dimensions of rotary files are introduced, the complexities of identification cause confusion. Hopefully, the common components of rotary files can eventually have standardized identifications for easier recognition.

The **flute** of the file is the groove in the working surface used to collect soft tissue and dentine chips removed from the wall of the canal. (Figs. 12, 13 and 14) The effectiveness of the flute depends on its depth, width, configuration and surface finish. The surface having the greatest diameter that follows the groove (defined as where the flute and land intersect), as it rotates, forms the leading (cutting) edge, (Figs. 12, 13 and 14) or the blade of the file that forms and deflects chips from the wall of the canal and severs or

snags soft tissue. Its effectiveness depends on its angle of incidence and sharpness. If there is a surface that projects axially from the central axis as far as the cutting edge, between flutes, this surface is called the **land** (Figs. 13 and 14) (sometimes called the marginal width). The land reduces the screwing-in tendency of the file, reduces transportation of the canal, decreases the propagation of micro-cracks on its circumference, gives support to the cutting edge, and limits the depth of cut. Its position relative to the opposing cutting edge and its width determine its effectiveness. In order to alleviate frictional resistance or abrasion resulting from a land, some of the surface area of the land that rotates against the canal wall may be reduced to form the **relief** (Fig. 14). The angle that the cutting edge makes with the long axis of the file is called the **helix angle** (Figs. 12, 13, and 14) and serves to auger debris collected in the flute from the canal.



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9. What is the core of a file?

The **core** (Fig. 15) is the cylindrical center part of the file having its circumference outlined and bordered by the depth of the flutes. The flexibility and resistance to torsion is partially determined by the core diameter. The core taper and total external taper can be different and the relative diameter of the

core, compared to the file's total diameter, may vary along its working portion in order to change the flexibility and resistance to torsion. The importance of the ratio of core diameter to total diameter is often overlooked in predicting a file's susceptibility to failure and can be different for each file size of the same series.

Fig.15 The central **core** circumference shown in cross-section of the K-3 file is determined by the boundaries of the depths of the flutes or is described as the largest diameter of the cross-section that has not been ground. The core taper may be less than the file taper in order to proportionately increase the file's flexibility toward the handle. A .04 tapered file can have a .02 tapered core, and the file would have proportionally less cross-sectional mass toward the handle and greater flexibility toward the handle than if the core taper and file taper were the same.

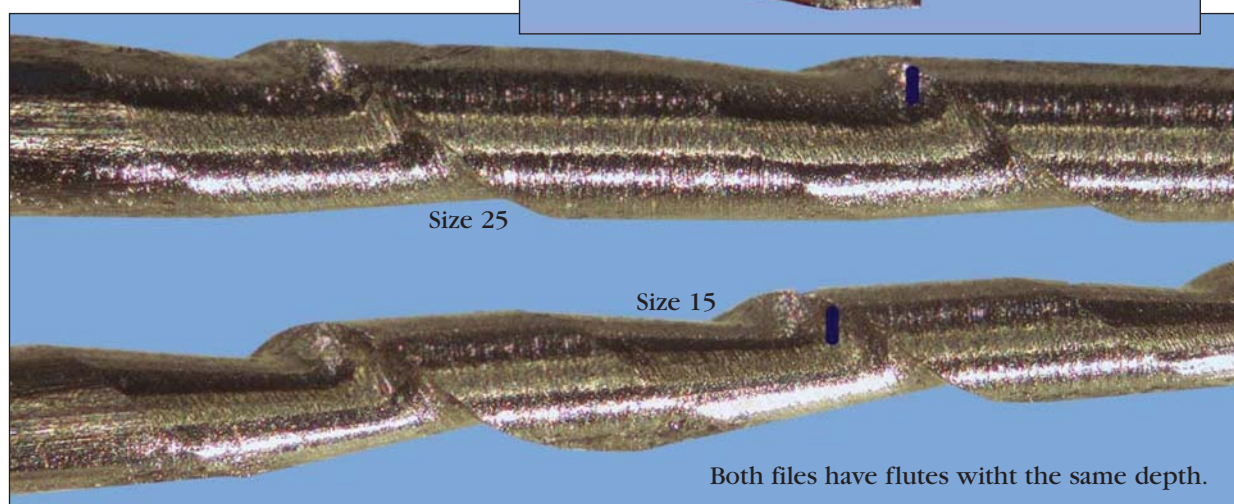
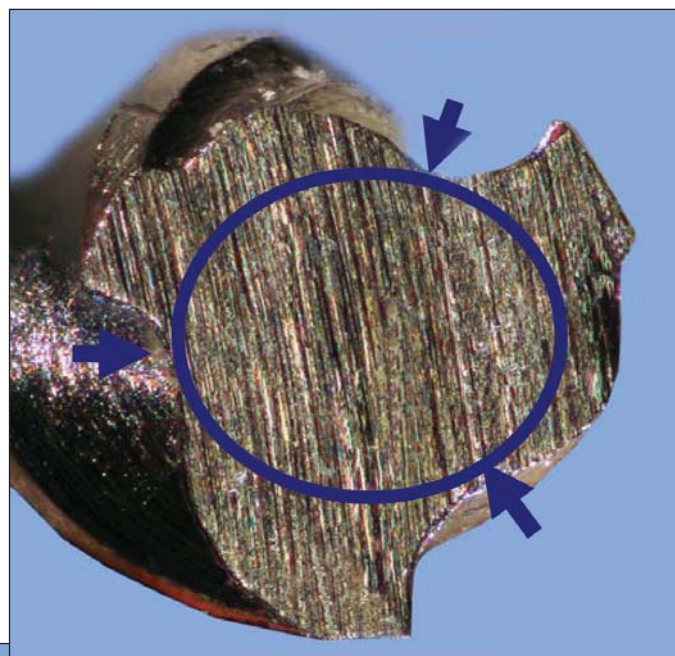


Fig. 16 Although the two files above have the same basic design and are of the same series, the ratio of the depth of the flute to the external diameter differs significantly. The depth of flute of the small instrument is approximately the same as for the larger instrument resulting in excess susceptibility to failure, whereas the larger instrument has adequate flexibility and adequate resistance to torsion failure.

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10. What is the difference between the rake angle and cutting angle?

If the file is sectioned *perpendicular to its long axis*, the **rake angle** (Fig. 17-29) is the angle formed by the leading edge and the radius of the file. If the angle formed by the leading edge and the surface to be cut (its tangent) is obtuse, the rake angle is said to be **positive or cutting**. If the angle formed by the leading edge and the surface to be cut is acute, the rake angle is said to be **negative or scraping**. However, the rake angle may not be the same as the **cutting angle** (Figs. 17-29). The cutting angle, **effective rake angle**, is a better indication of the cutting ability of a file and is obtained by measuring the angle formed by

the cutting (leading) edge and the radius when the file is sectioned *perpendicular to the cutting edge*. In some instances, as with some Quantec files, a file may have a blade with a negative rake angle and a positive cutting angle. If the flutes of the file are symmetrical, the rake angle and cutting angle will be essentially the same. Only when the flutes are asymmetrical are the cutting angle and rake angle different. Both angles may change as the file diameters change and may be different for file sizes.

The **pitch** of the file is the distance between a point on the leading edge and the corresponding point on the adjacent leading edge along the working surface, or it may be the distance between points within which the pattern is not repeated. The smaller the pitch or the shorter the distance between corresponding points, the more spirals the file will have and the greater the helix angle will be. Most files have a variable pitch, one that changes along the working surface, because the diameter increases from the file tip towards the handle and the flute becomes proportionately deeper resulting in a the core taper that is different from the external taper. Some

Direction and Action of the Leading Edge (angle of incidence)

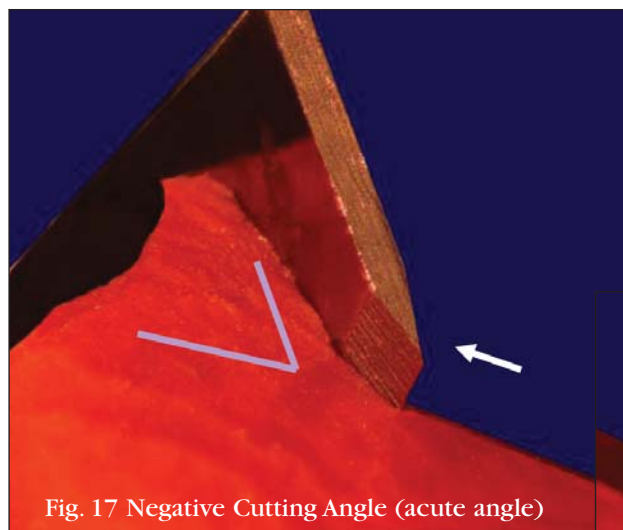
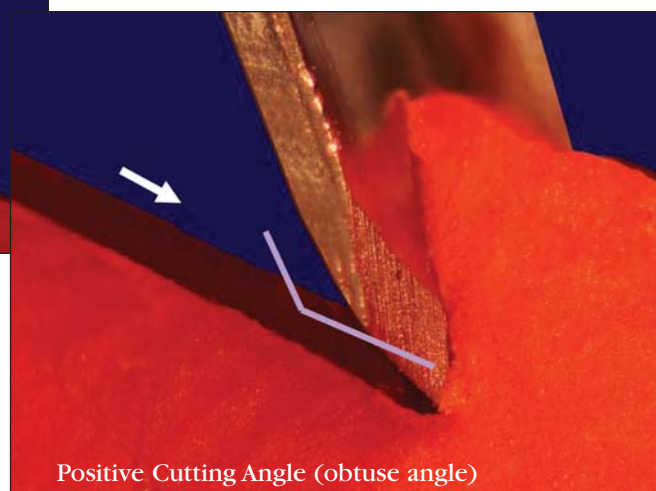


Fig. 17 Negative Cutting Angle (acute angle)

Negative angles result in a "scraping" action. Positive angles result in a cutting action. Although cutting actions can be more efficient and require less force for enlarging a canal, a scraping action may have a smoother feel. The operator may erroneously confuse smoothness with efficiency. However, if excessive pressure is applied to a cutting file, a larger chip may require more force to dislodge and excessive torsion could be the result (arrows indicate the direction of the blade motion).



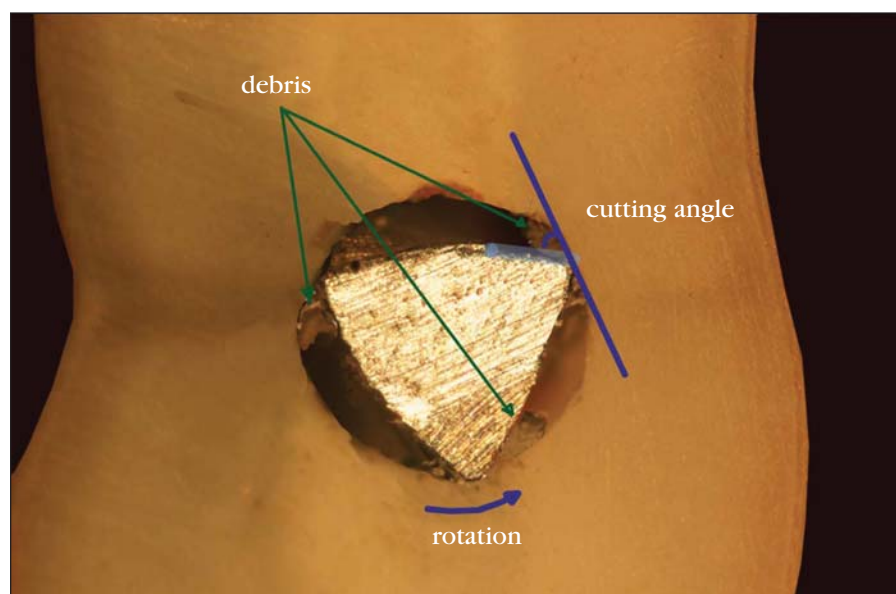
Positive Cutting Angle (obtuse angle)

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instruments, such as the Quantec and K-3 files, have asymmetrical cross-sectional designs in which case the pitch may be considered to be the distance between points that the pattern is not repeated.

The cutting angles, helix angles, external and core taper may vary along the working surface of the file and the ratios of these

quantities can vary between instruments of the same series. Any change of any of these features can influence the file's effectiveness or its propensity for breakage as it progresses into the canal space and can account for some files to act uncharacteristically when compared to files that have different dimensions in the same series.



The ProTaper file utilizes a negative angle of incidence to enlarge the canal. The surface of the file blade meets the canal wall with an acute angle resulting in a scraping action. More pressure is required when enlarging the canal in this manner

Fig. 18

The K-3 file utilizes a slightly positive angle of incidence to enlarge the canal. The file blade meets the canal wall with an obtuse angle resulting in a cutting action. Less pressure is usually required when enlarging the canal in this manner. Excessive pressure can cause excessive torsion by forming chips too large to be dislodged.

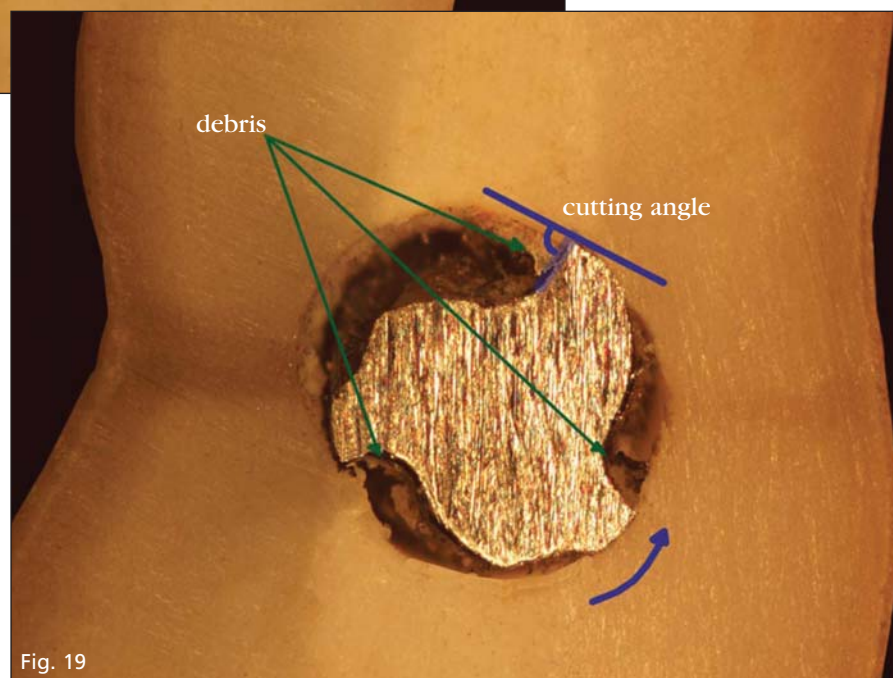


Fig. 19

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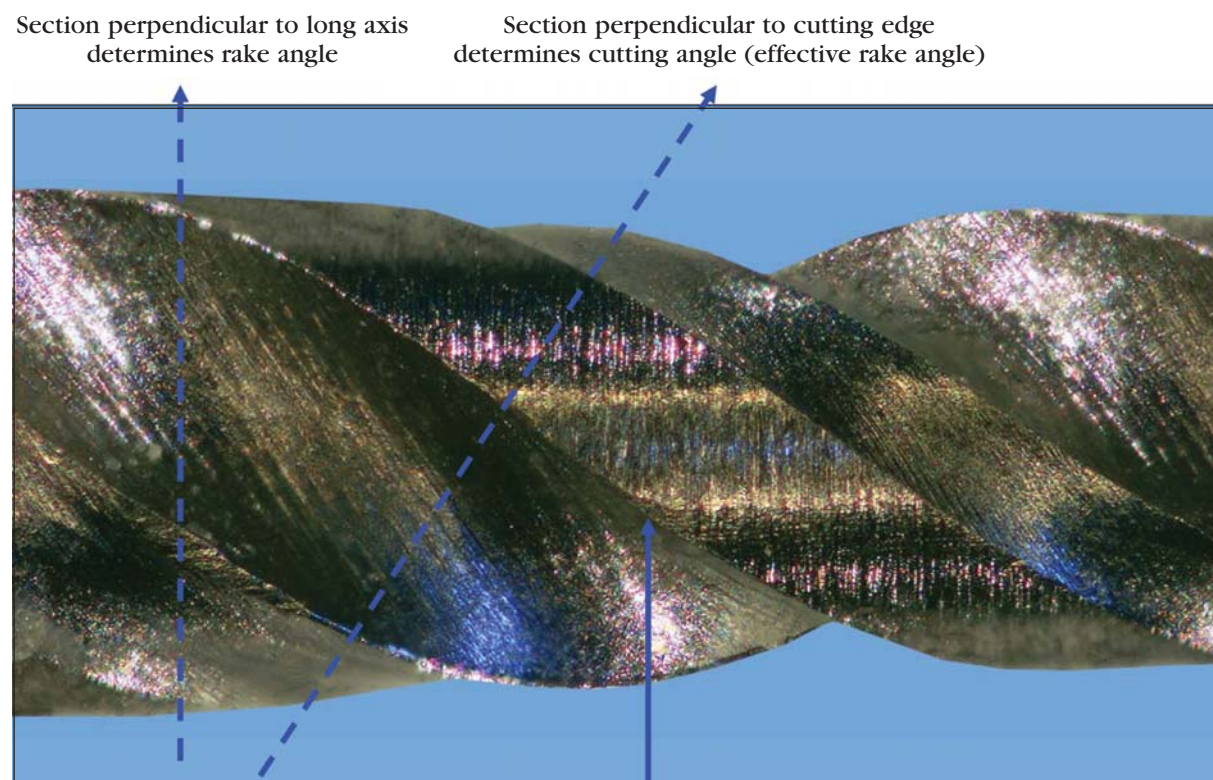


Fig. 20 Quantec File.

Cutting edge

The cutting angle, effective rake angle, is a better indication for determining the cutting ability of a file than the rake angle, because it shows the actual angle of incidence.

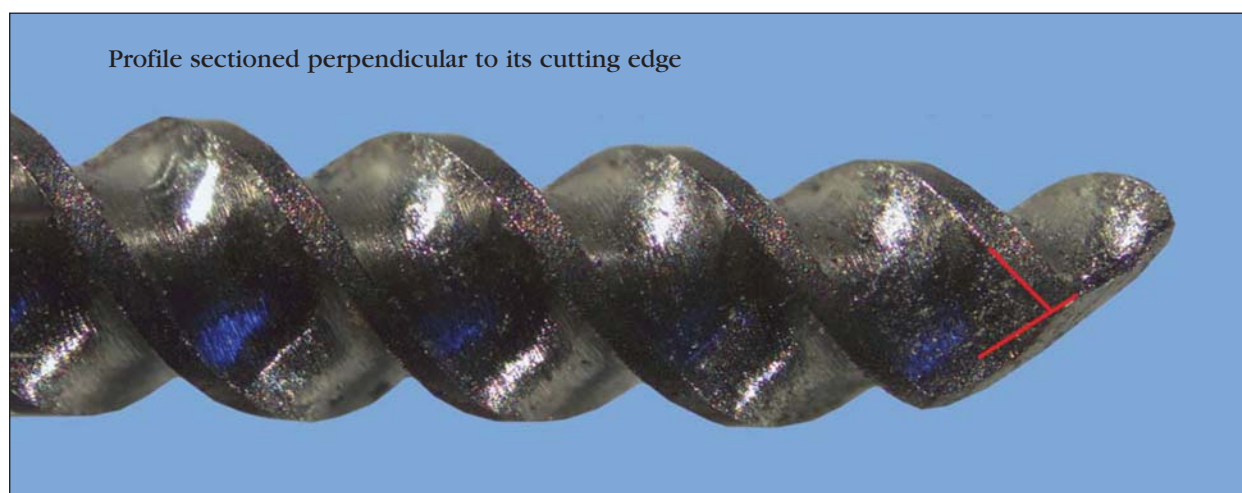


Fig. 21

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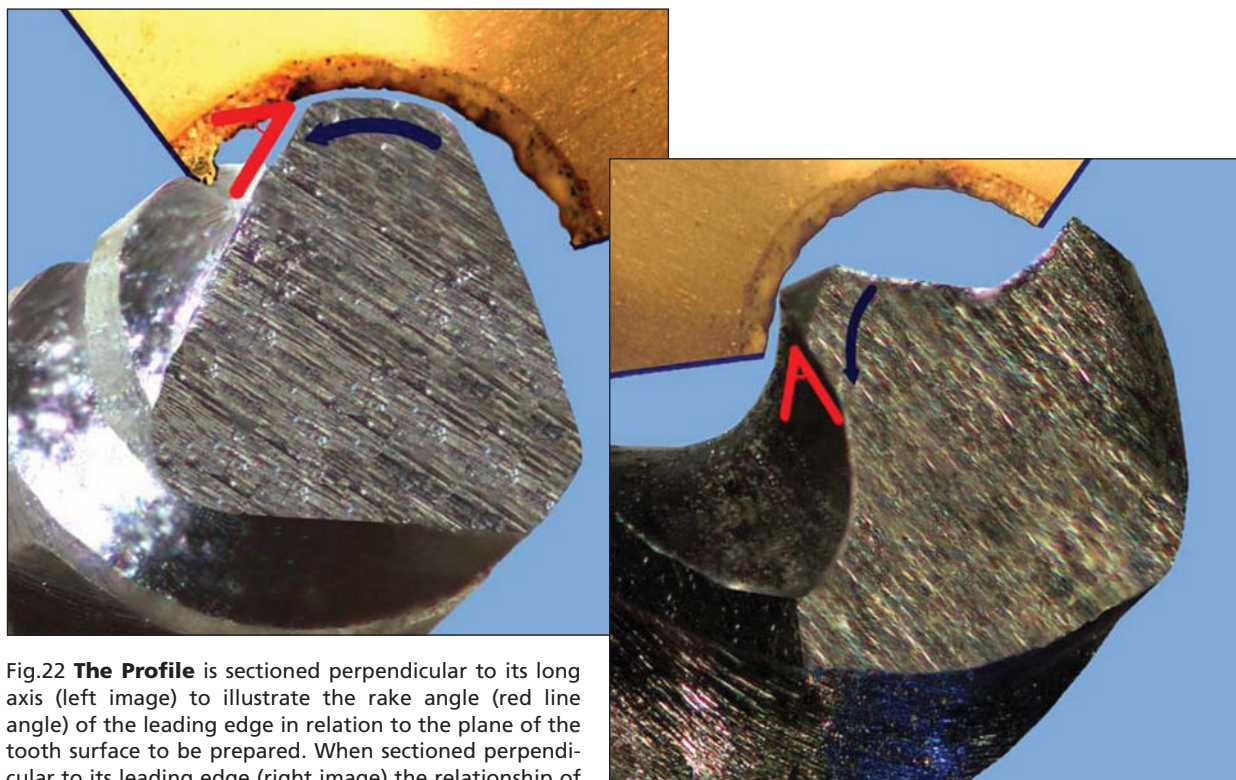


Fig.22 **The Profile** is sectioned perpendicular to its long axis (left image) to illustrate the rake angle (red line angle) of the leading edge in relation to the plane of the tooth surface to be prepared. When sectioned perpendicular to its leading edge (right image) the relationship of the cutting angle (red line angle) and the tooth surface to be prepared have the same relationship as in the perpendicular to the long axis section. The rake angle and cutting angle are the same because the flutes are symmetrical on the Profile.

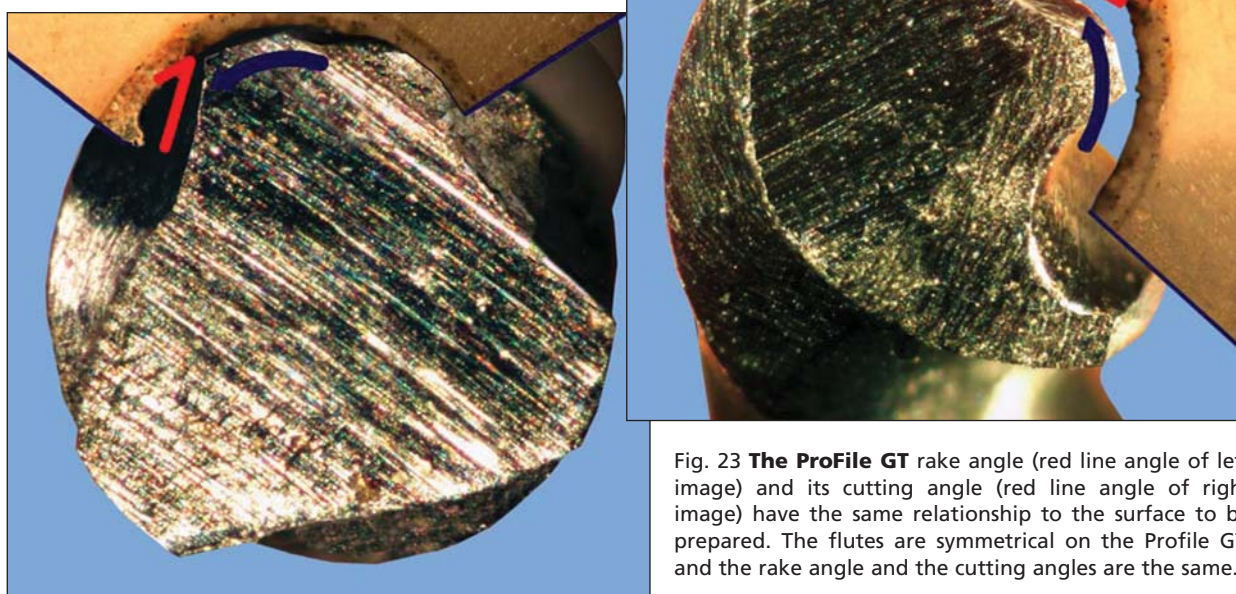


Fig. 23 **The Profile GT** rake angle (red line angle of left image) and its cutting angle (red line angle of right image) have the same relationship to the surface to be prepared. The flutes are symmetrical on the Profile GT, and the rake angle and the cutting angles are the same.

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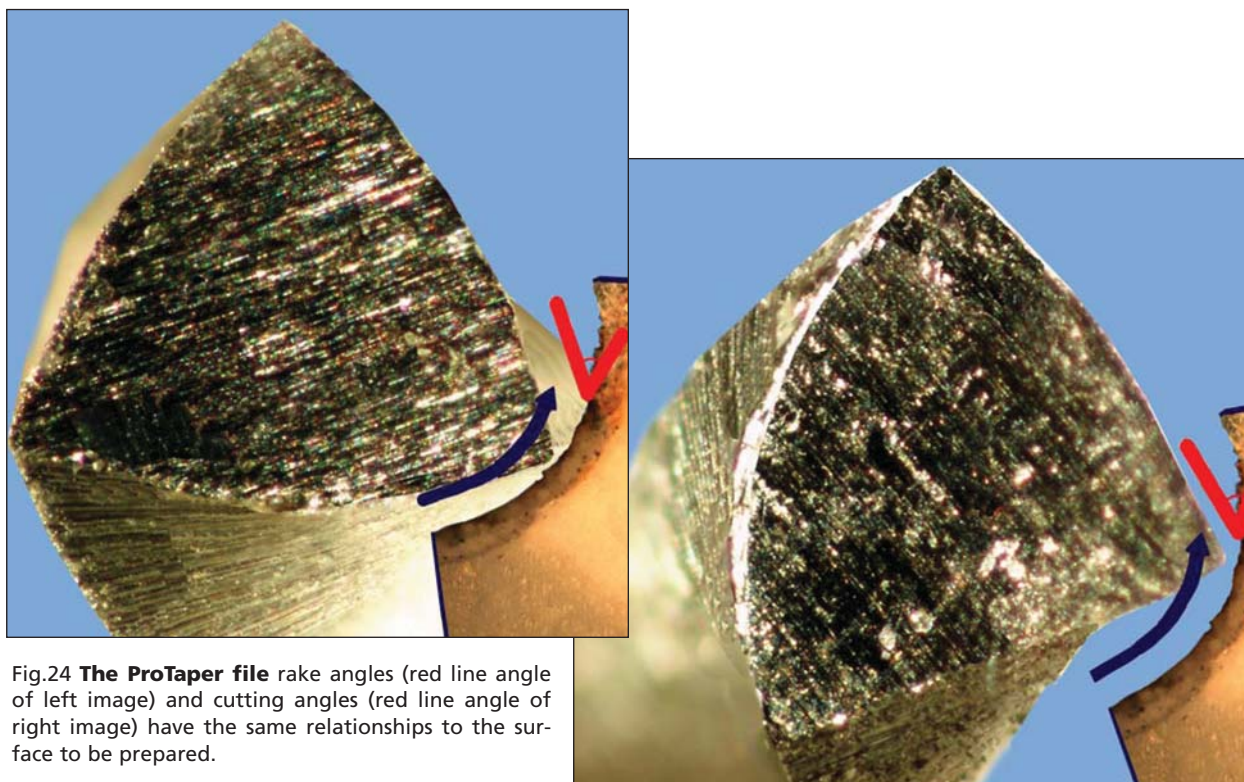


Fig.24 **The ProTaper file** rake angles (red line angle of left image) and cutting angles (red line angle of right image) have the same relationships to the surface to be prepared.

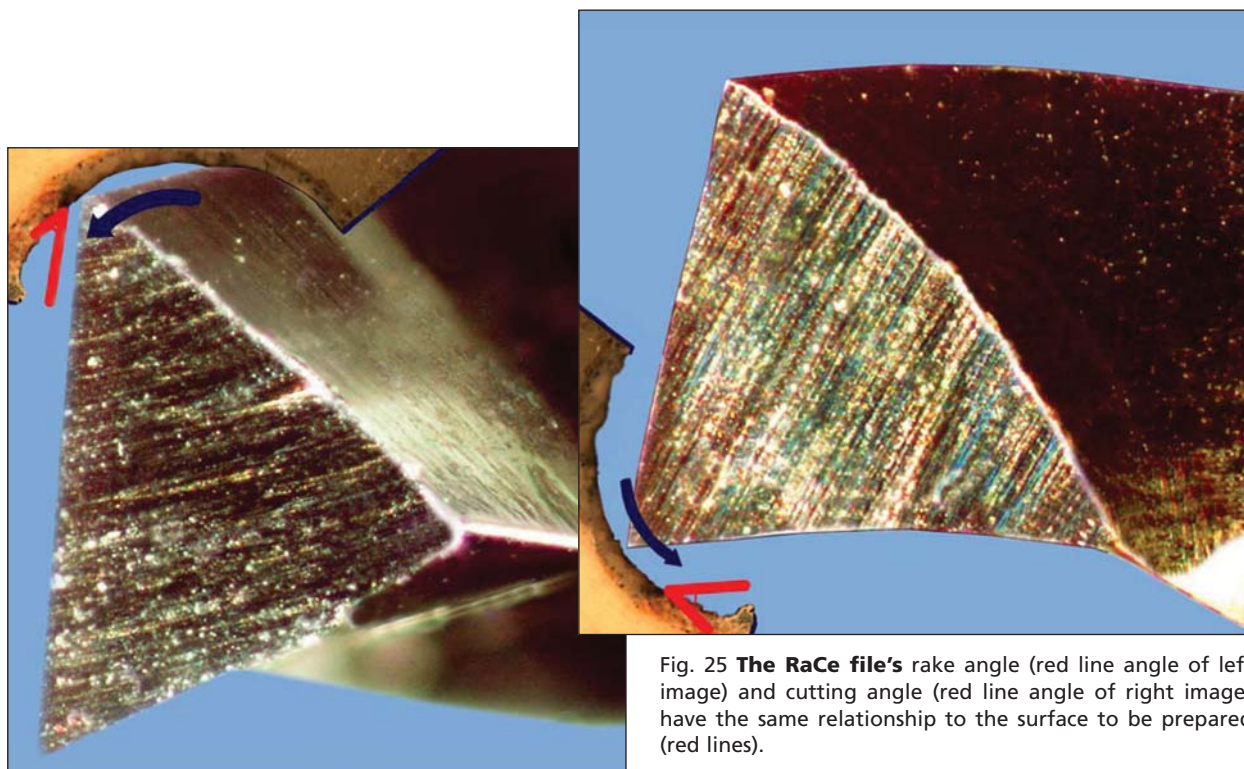
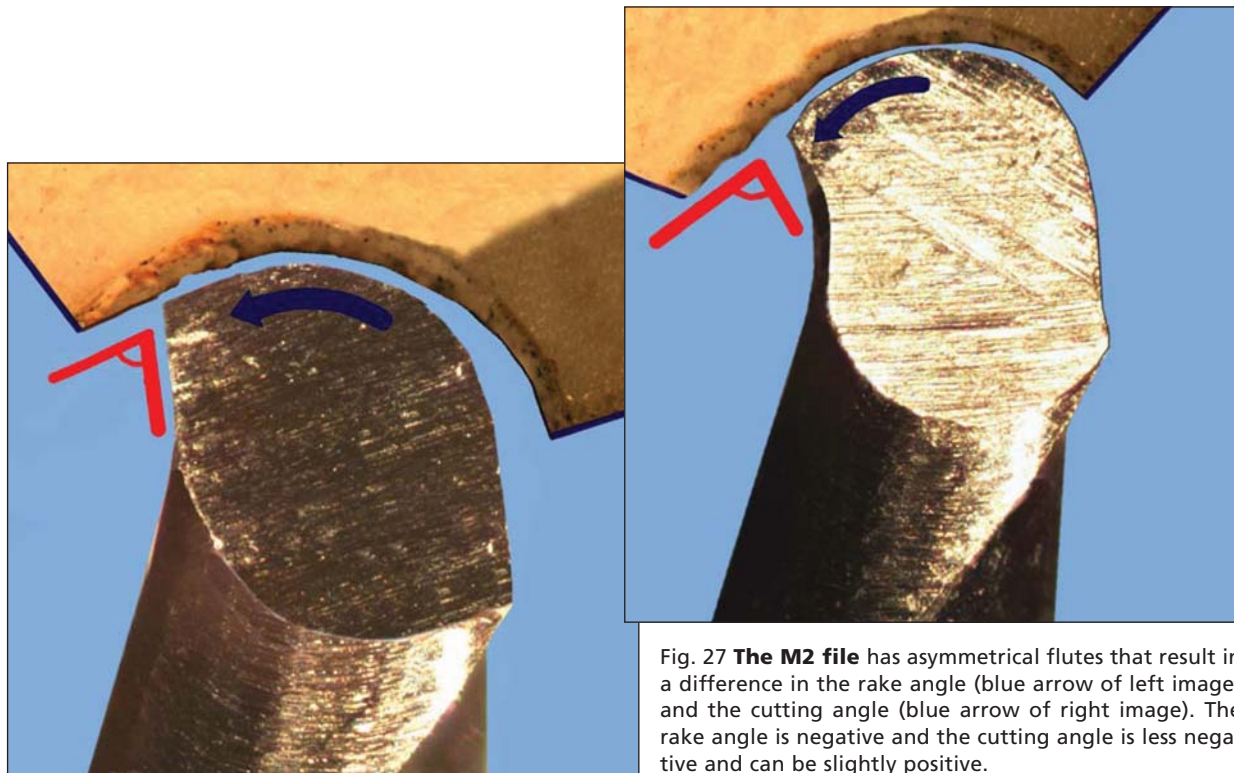
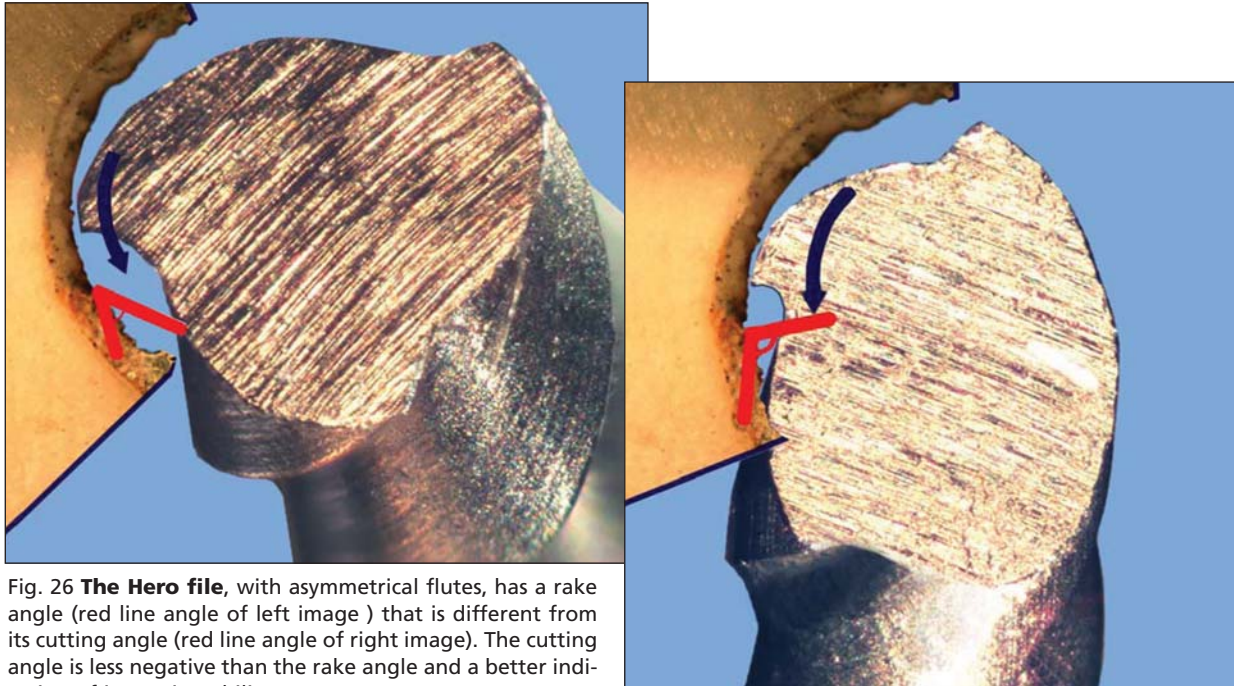


Fig. 25 **The RaCe file's** rake angle (red line angle of left image) and cutting angle (red line angle of right image) have the same relationship to the surface to be prepared (red lines).

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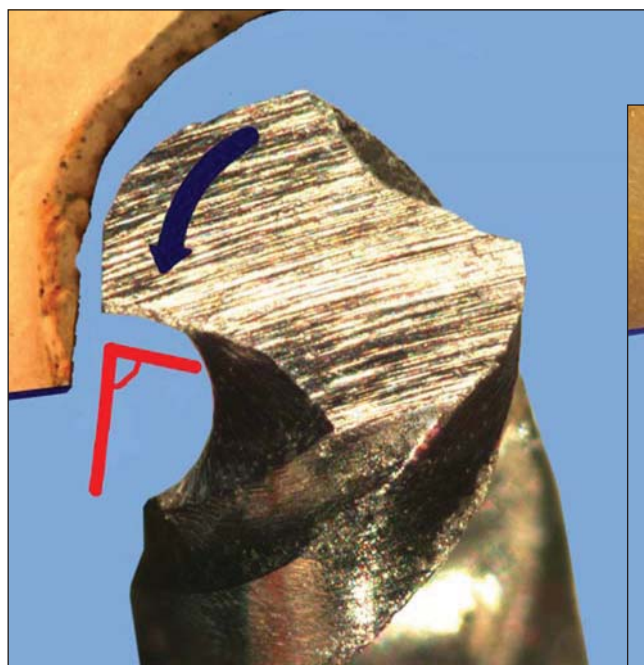


Fig. 28 **The Quantec file, which has asymmetrical flutes,** has a negative rake angle (red line angle of left image) and a positive cutting angle (red line angle of right image).

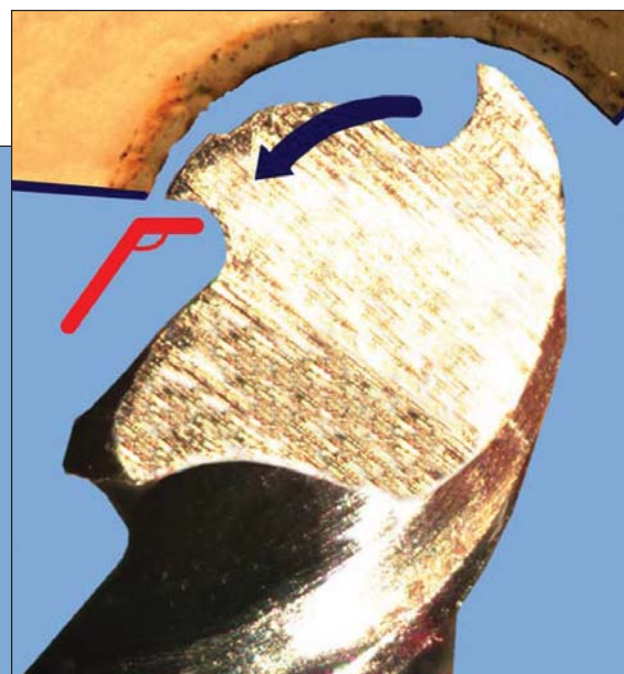
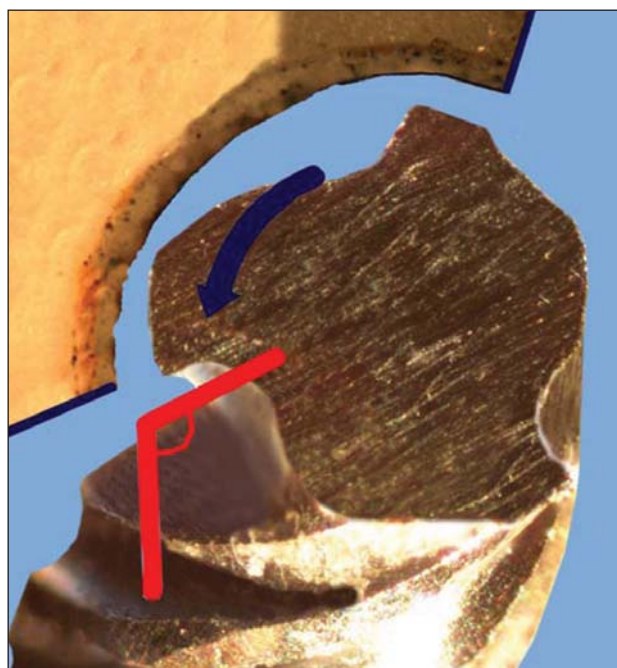
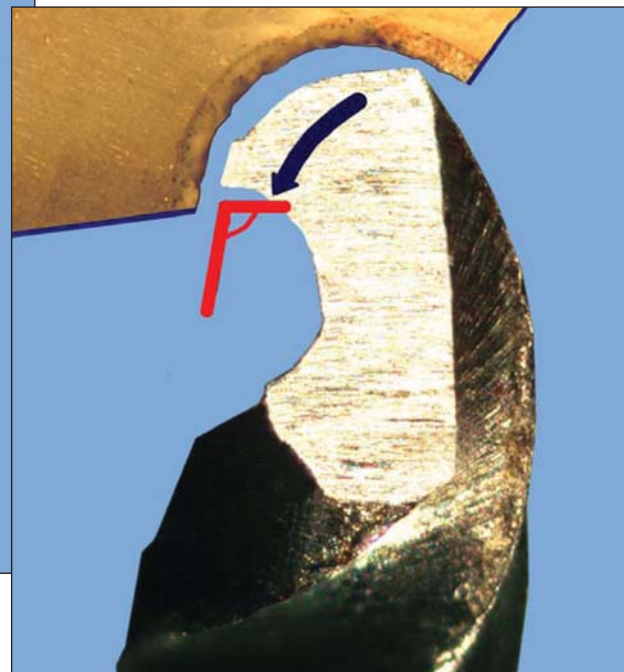


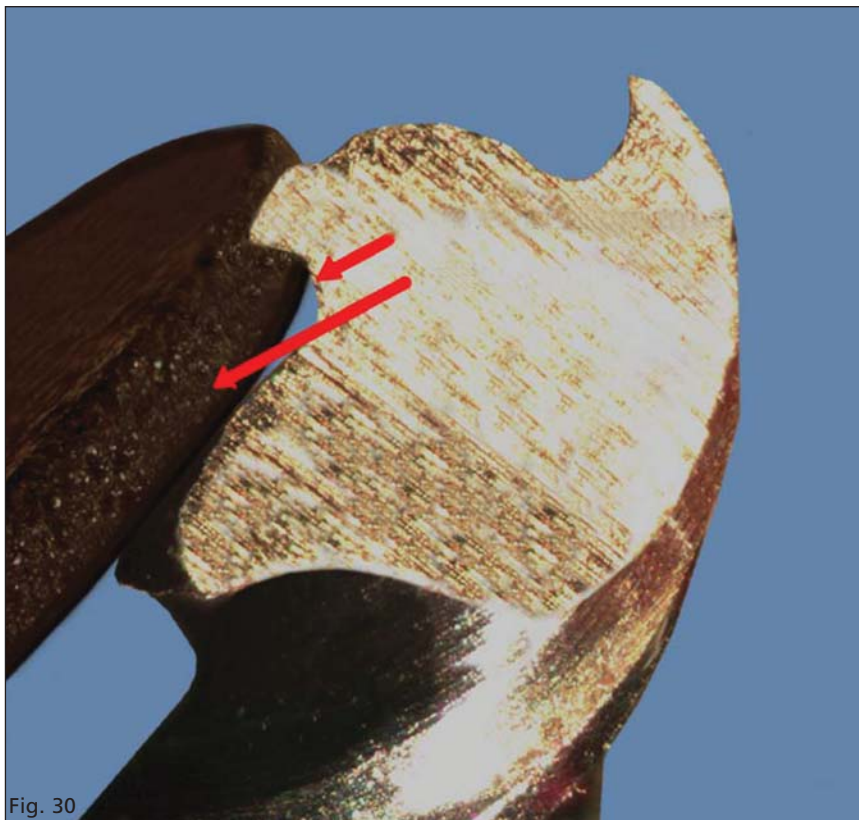
Fig. 29 **The K3 file** can have a positive rake angle (red line angle of left image) depending on the diameter sectioned but has a definite positive cutting angle (red line angle of right image).

11. Why are the rake angles and cutting angles the same on some files and not on others?

All nickel-titanium files begin as round wires. When files are manufactured with conventional grinding processes, the wire transverse a grinding wheel to form a flute (groove) in the side of the wire. If the wire is rotated, as it is fed across the grinding wheel, a spiraled flute is formed having a helix angle (the angle of the flute with the long axis of the file), and the shape of the flute is formed by the shape and angulations of the grinding wheel. Positive **rake** angles are difficult to accomplish due to the size of the grinding wheel relative to the file diameter. However, by adjusting angulations of the grinding wheel, positive **cutting**

angles are more easily accomplished. Of all the current spiraled instruments, positive rake angles, of at least one blade, exist only on the larger diameters of K3 files. However, it is conceivable that other H-type (Hedstrom) instruments could incorporate positive rake angles.

Files that have **symmetrical** flutes will not have positive rake or cutting angles and both of these angles will be essentially the same. Any positive cutting angle is the result of the flute having a smaller radius (**asymmetrical**) adjacent to its cutting edge as compared to the radius of the remaining portion of the flute. By varying the depth and/or asymmetry of the flute, the cutting edge of the file can be adjusted to become more or less positive along its working length, in order to enhance its effectiveness.



Grinding angle for asymmetrical flute (sectioned perpendicular to the cutting blade)

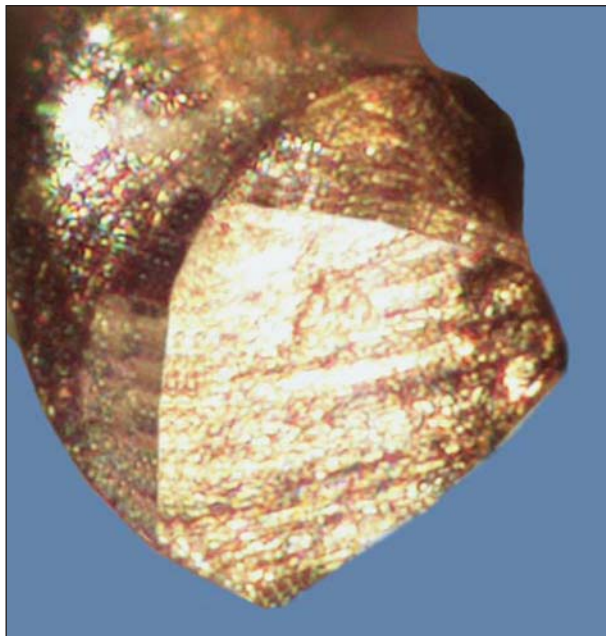
The grinding wheel during fabrication of the K-3 file forms a positive cutting angle by grinding a smaller radius on one side of the flute (asymmetrical).

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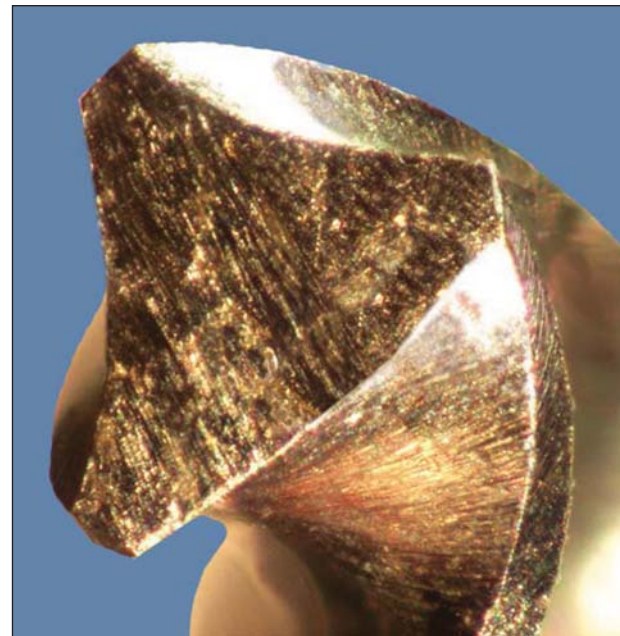
12. Do cutting angles change along the working surface of a file?

If the flute design of a file has no radius (the flute is a flat surface) when viewed in its cross-section, the cutting angle will remain the same along its working surface from D1 to D max. Without a radius, the depth of the flute in its cross-section will be outlined as a straight line. The only files having that design are the K-type file and reamer, the RaCe file, the Sequence file, and the Liberator file. Although there are exceptions, as is the Hero file, any file that has a cross-sectional design with an asymmetrical radius may likely have a cutting angle that changes along its working

surface. The flutes of these files usually occupy proportionately less of the cross-sectional area at their tips than at their largest diameters for two reasons. One reason is the intentional design to provide a more rigid tip and the other reason is the limitation of manufacturing capabilities. Consequently, the cutting angles near the tips would be less positive than at their larger diameters and the tips of these files have comparatively less flexibility but more resistance to torsion stress. If one attempts to mentally determine the cutting action of a file by viewing its cross-section, it is important to keep in mind that the cross-section design may change along the working surface and may be substantially different from the manufacturer's representations.



Profile GT sectioned at .35 mm. diameter



Profile GT sectioned at .90 mm diameter

Fig. 31

Although the ProFile and ProFile GT series of files are usually portrayed as having a U-file having a flute with a radius with neutral rake angles, diameters smaller than .6 mm have flutes that are essentially straight in cross section. The radius of the flute is limited by the radius of the grinding wheel during the manufacturing process

13. What is an aggressive file?

Efficiency is defined as the ratio of the work done to the work equivalent of the energy supplied to it. An efficient file, a file having greater cutting ability, requires less time, torque and/or pressure to accomplish canal preparation. The less pressure, torque and time required, the more likely file failure can be prevented. The *concept* is often confused, however, by describing a more efficient file as a more aggressive file, a term that seems to be used with a negative connotation. Aggressive forces of the operator on an efficient file are unnecessary and can be counter-productive. For example, if one pushes with excessive pressure on an efficient file the chips that are formed on the wall of the canal can be larger than can be removed without requiring significantly more torque than would have been required for forming and removing smaller chips with less pressure. Clinicians who change file systems and

begin working with more efficient files often have a tendency to apply the same time or force as was required with less efficient files. The excessive (aggressive) force on the more efficient file should be avoided and the clinician will enhance the quality of preparation and reduce the threat of failure by learning to match the file's efficiency with the level of force required. Without the benefit of efficiency data, clinicians often choose less efficient files because of the tactile sensations perceived. A file that enlarges a canal with inefficient scraping actions, for instance, can "feel" smoother than a file that uses cutting actions. **How an instrument feels during use is not a reliable indication of its efficiency.**

The major concern for an efficient instrument is its ability to transport the canal. It should be remembered that **time** as well as **force** are functions of efficiency and less time will be required to transport as well as

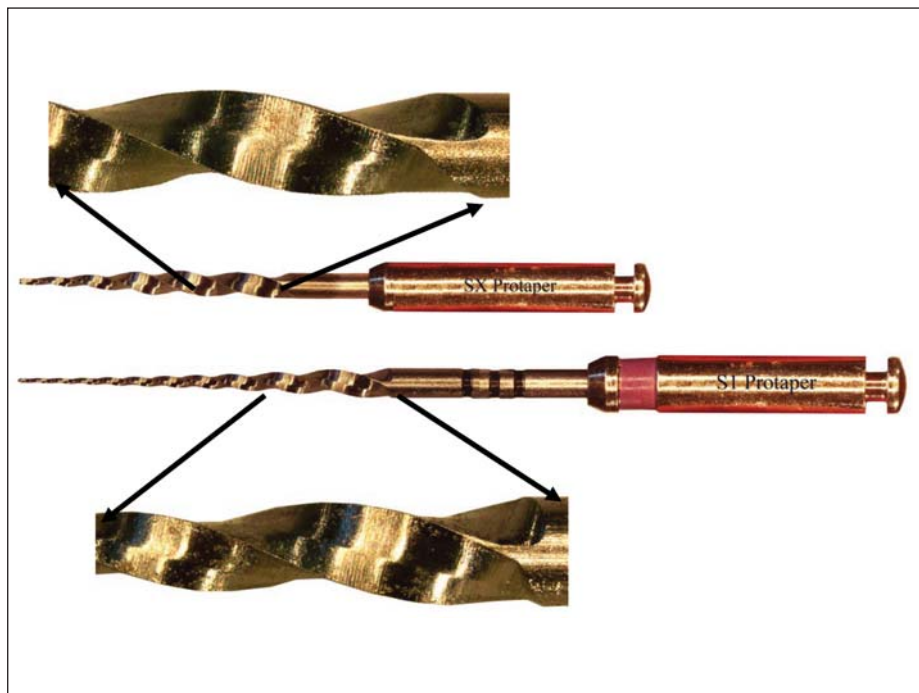


Fig. 32 The S1 and the SX ProTaper files have the same cross-section design and maximum diameter. However, slight dimensional differences of the S1 enable it to have greater cutting efficiency (generating less torsion) when engagement is limited to the maximum diameters. (Refer to Chart 50)

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to enlarge a canal with an efficient file. On the other hand, the less efficient file requires more time that results in more rotations and greater fatigue, and/or more force that results in greater torsion. The additional fatigue and torsion, of course, increase the possibilities of breakage.

One should also keep in mind that a file cannot transport unless it was at first where it should be, and only the excessive time it remains in that position results in transportation. **Once a file has rotated one time in one position, the canal will be enlarged to the file's diameter and to avoid transportation the file should not remain in that position once the canal is enlarged.** Even very minor differences in file design dimensions can affect the cutting efficiency of files and their propensity for transporting canals.

14. What are the functions of lands?

Lands are the surfaces of files that extend as far axially from the center as the cutting edges that define the file's circumference. Lands are used to reduce screwing-in forces, support

the cutting edge, reduce transportation, and limit the depth of cut in much the same manner that a safety razor functions. The surface of a land reduces the tendency of faults caused by stress or manufacturing imperfections in the metal to propagate along its cutting edge or circumference. Lands need not be very wide to function.

The force of abrasion is a direct result of the surface area of a land that rotates against the wall of the canal. Wide lands can result in excessive abrasion forces that increase the torque requirements for rotation. In addition, faster rotations of a file cause the lands to further limit the depth of cut, and wide lands on larger files can prevent the blades from engaging an adequate depth into the canal. Wide lands can be very useful in small diameter files by adding rigidity and by enabling the file to negotiate curvatures when canal enlargement is minimal. When lands are too wide for effective canal enlargement, the files can be used very effectively for removing gutta percha from the canal and for circulating irrigation in the canal.

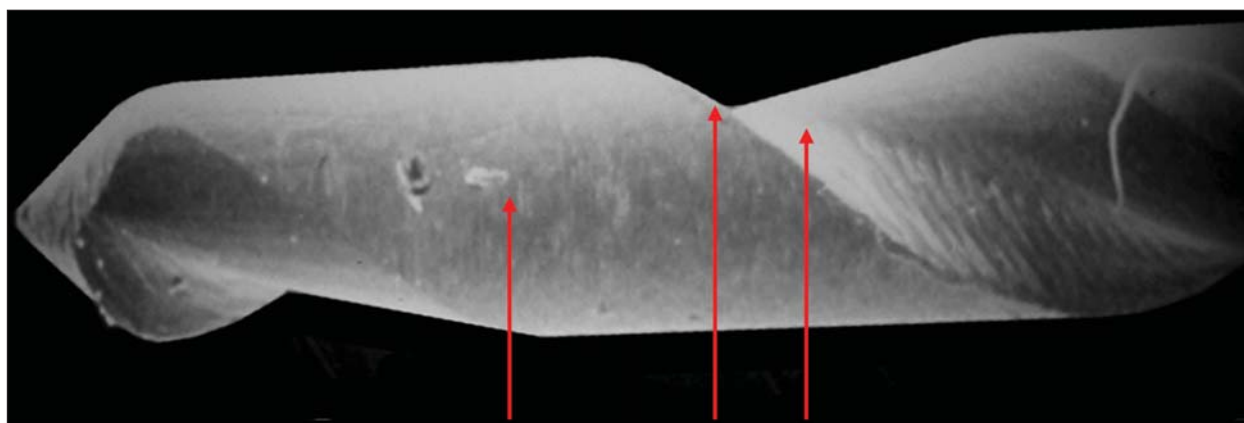


Fig. 33

Land Leading edge Flute

The GPX instrument, Brasseler USA, is used for removing gutta percha from the canal. The friction of the wide land rotating against gutta percha causes it to plasticize while the spirals auger it from the canal. The instrument is very effective for removing gutta percha but is ineffective as a larger size file because the land occupies most of the working surface and keeps the leading edge from engaging into the canal surface.

Mastering Endodontic Instrumentation

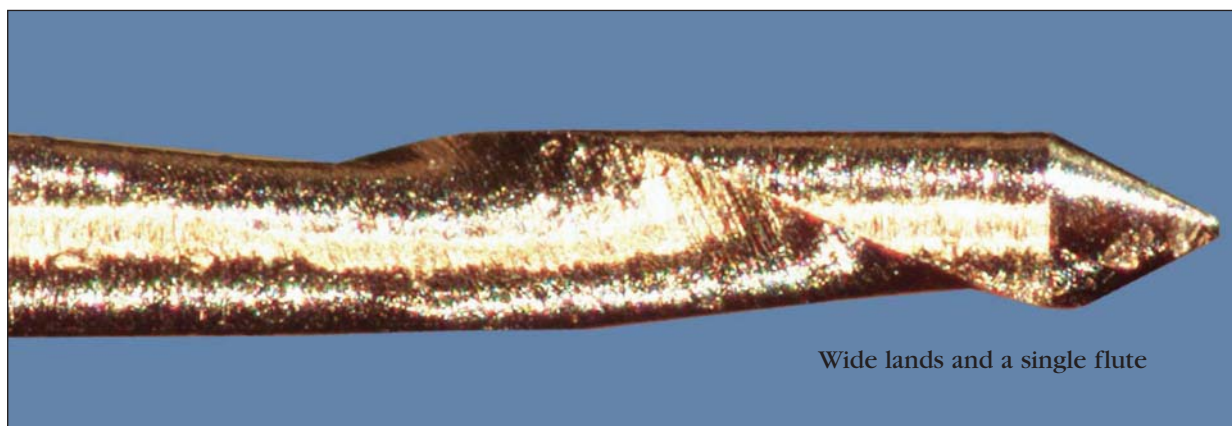


Fig. 34 The **Endomagic** file (size 15) utilizes wide lands for smaller size files to facilitate negotiating curvatures.

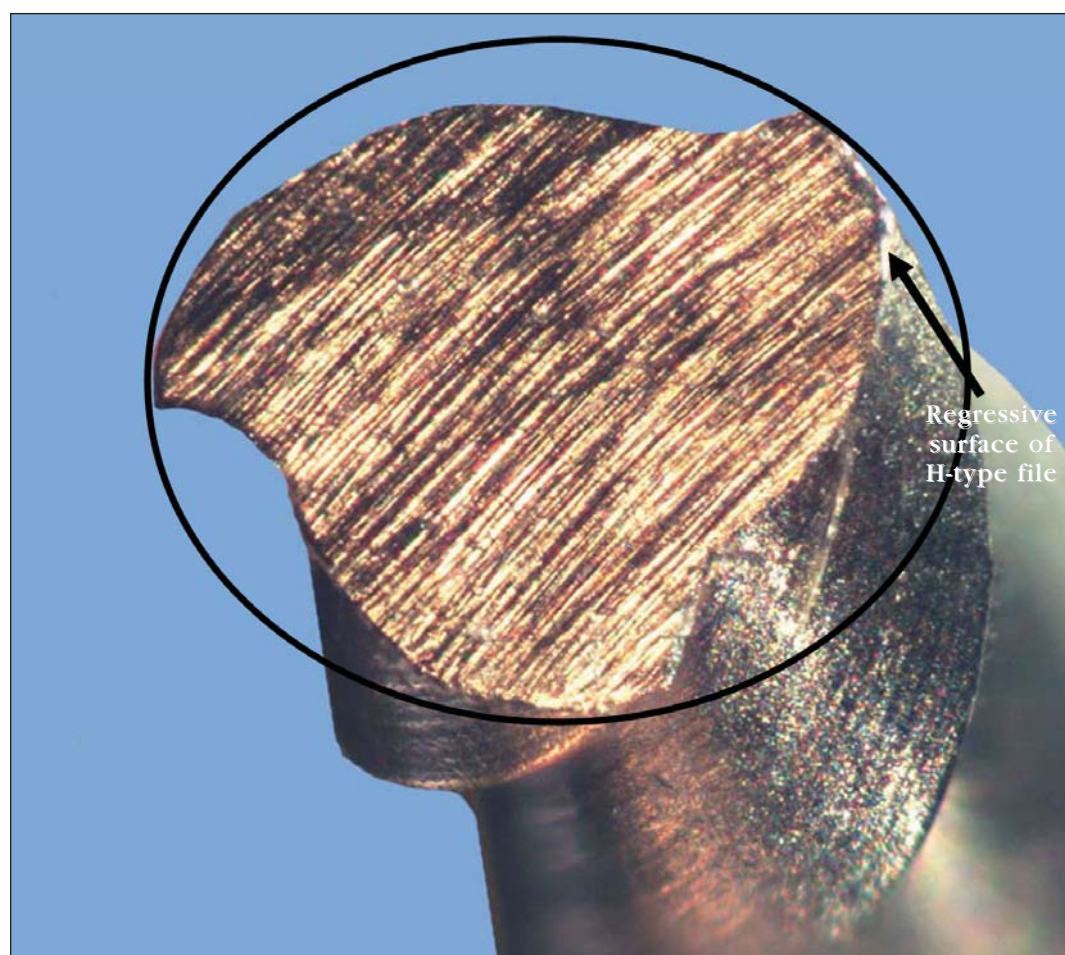


Fig.35 **Hero file cross section.** Although not technically lands, since the surface does not extend axially from the center of the file as far as the cutting edge, H-type files have surfaces that follow the blades that gradually retreat from the file's circumference.

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A **recessive** surface that follows the blade on H-type files gradually recedes from the file's outside diameter, provides support of the blade, and reduces propagation of cracks along the blade in the same manner as lands, but lacks some of the effectiveness in avoiding canal transportation. However, the force of abrasion is reduced. Rotary files having this design include the three-fluted Hero file (MicroMega) and the newly introduced two-fluted M2 file (Sweden Martina). The M2 file is essentially a modification of

the Dynatrac file and NT file design, having positive cutting angles but having fewer spirals. This modification is attributed to Dr. Vinio Malignino of Italy. Another modification is the LA Axxess file, which has a surface that at first gradually retreats from the blade, but becomes a flat recess or relief. This file is used primarily to intentionally transport the canal orifice and utilizes the piloted tip like the Dynatrac to minimize canal transportation at the tip. This design is attributed to Dr. Steve Buchanan.



Fig. 36 **Dynatrac file**. This file was the first multi-fluted H-type file to have a non-cutting pilot. Made of stainless steel, it was used in a reciprocating handpiece to avoid fatigue. (Designed by J. McSpadden, 1977)



Fig. 37 **Hero file**. Even though this file has about the same pitch as the Dynatrac file, its three flutes result in a helix angle for less screwing-in forces during rotation. (Micro-Mega)

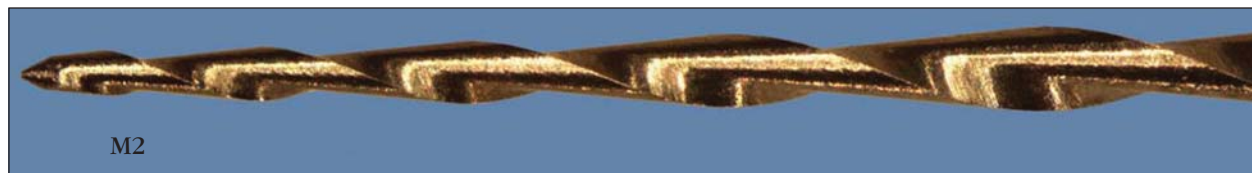


Fig. 38 **M2 file**. This 2-fluted H-type file has the same cross-section design as the Dynatrac file but has a longer pitch that is more suitable for rotation.



Fig. 39 **LA Axxess file**. Designed for preparing the canal access, this stainless steel file has much the same design as the Quantec file except it has no land following its cutting edge since it is not meant to negotiate curvatures.

15. Do the designs of files have to be limited to a grinding process during manufacturing?

The capabilities for fabricating complex file designs have increased dramatically with computerized multi-axis grinding processes. However, any process of grinding limits the shape and strength of files. The size of the grinding wheel limits the file's shape, and cutting across the grain of the crystalline structure of the wire limits its strength. The process of **electrical discharge machining, (EDM)**, is a promising alternative means of manufacturing endodontic files. The shape of the file is formed by electric spark erosion of a wire. EDM manufacturing alters the molecular structure on the file's surface potentially strengthening the file without affecting its flexibility.

Another promising method for manufacturing nickel titanium files is using the **process of twisting** that was used for fabricating steel files for decades but was initially thought to be an impractical method for nickel titanium. Residual stress and the problem of shape memory for nickel titanium can be avoided during this process by heat-treating before, during or after twisting. The helix angle can be varied along the working surface by using a computerized twisting process. The rationale for using this manufacturing technique is that

work hardening the metal by twisting might occur as it does during the twisting process of stainless steel files, and enhance its strength while maintaining greater integrity of the crystalline structure. Alternative manufacturing also includes flute formation by forcibly pushing a blade into a tapered wire. A **furrowing process** forms the flute rather than being ground and the blade becomes projected from the shaft either with a continuous furrow or intermittently to form barbs. Barbed broaches are manufactured by this process. The file shape can actually result from being pressed or impacted into the NiTi wire.

The molecular structure of conventional metals is organized into grains or crystals. The boundaries between the crystals are the areas of weakness where failure occurs when undergoing excessive stress. Scientists have discovered that if some alloys are cooled very quickly during the process of casting, crystallization can be avoided. One of the most unique developments for the potential for fabricating complicated file designs incorporates this **process of casting** and avoids many of the limitations of grinding altogether. The resulting metal has an amorphous non-crystalline structure, the properties for accommodating stress are enhanced, and the microscopic irregularities caused by the grinding wheel that result in stress concentration points are eliminated.



Fig. 40 **Liquidmetal** cast file (the handle and shaft are cast as one piece). Casting allows the blades to be designed to spiral only 180 degrees around the shaft in order to reduce canal wall engagement. It also allows each blade to have a different helix angle to avoid screwing-in forces. Continuous advancements in casting techniques can make it a viable manufacturing process in the near future.

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16. Does the quality of manufacturing make much difference?

Before different types of files are studied, it should be stressed that the quality of manufacturing is the most basic consideration for determining the success or failure of files independent of its composition or design. Less than ideal manufacturing quality controls result in the formation of micro-cracks and defects along the surface of a file.

Cracks can propagate to failure at a stress level lower than the stress ordinarily encountered during instrumentation and other defects can cause stress concentration points that

lead to file failure and jeopardize endodontic success. It should be pointed out that considerably less force is required to propagate a crack than is required to form it. It is not surprising to find that fatigue cracks in files usually start at geometrical irregularities on a macro- and micro-scale. If the defects are in a position of high stress, failure can occur quickly. The area of highest stress is along the blade or leading edge. Failure is the result of stress per unit area so a blade that is unsupported by a land, such as a file having a triangular cross-section, will have greater forces for failure than a blade supported by a land or regressing circumference.

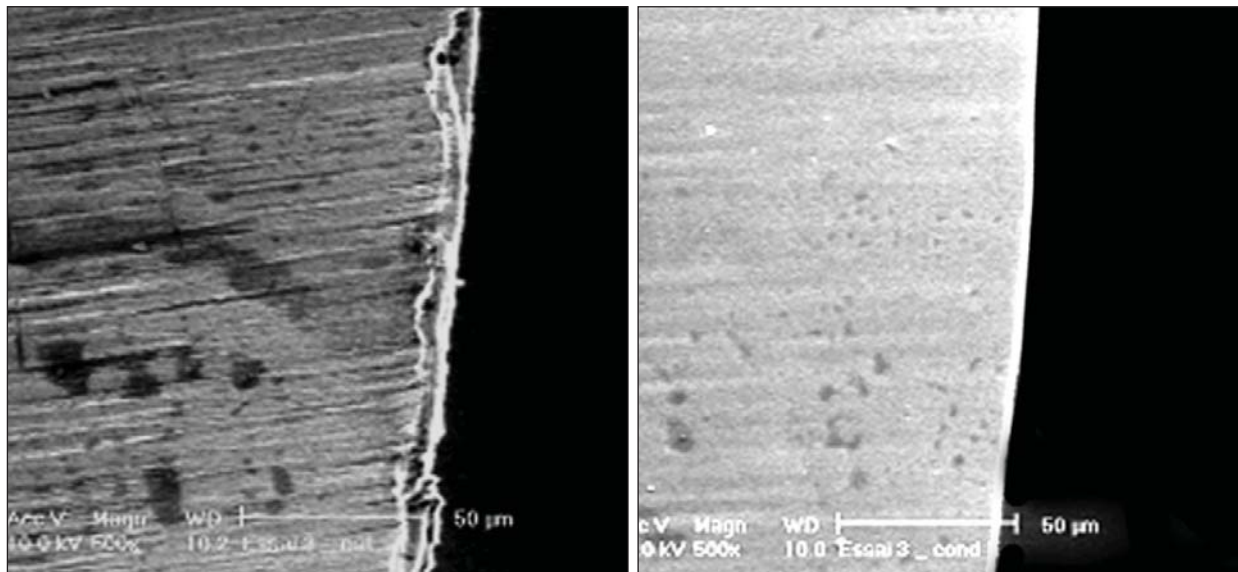


Fig. 41 **Before and after** surface treatment during manufacturing.

The formation of micro-cracks (shown on the file's cutting edge in the left photograph) during initial production of files by FKG Dentaire SA was later eliminated by a special surface treatment process. (shown in the right photograph) and resulted in increasing the resistance to torque failure by as much as 1000% in some samples. Files were compared rotating in a glass tube (inside diameter 2 mm, 90 degree curvature and 8 mm radius) at a speed of 350 rpm until failure.

Design Considerations:

17. What are the most important relationships of the components of file designs and canal anatomies that enable us to improve our technique?

Careful examination of technique and design considerations identifies the limitations and usefulness of existing instruments and facilitates the development of a new generation of rotary instruments and techniques, one unencumbered by traditional concepts. A few all-important consequential relationships of different file designs and tooth anatomies are useful in understanding how files function. Although research on endodontic instruments cannot determine with absolute certainty how files will react under all circumstances, research can result in inferences having significant predictability that can be used as considerations for instrument and technique design. The following are some of the considerations and ramifications of designs that are most important in formulating techniques in approaching difficult cases:

- 1. A file with a more efficient cutting design requires less torque, pressure or time to accomplish root canal enlargement.**
- 2. In a straight canal, the ability of a file to withstand torsion is related to the square of its diameter.**
- 3. In a curved canal, the ability of a file to resist fatigue has an inverse relationship with the square of its diameter.**
- 4. The torque required to rotate a file varies directly with the surface area of the file's engagement in the canal.**
- 5. Fatigue of a file increases with the number of rotations of the file in a curvature.**
- 6. Fatigue of a file increases with the degree of curvature of the canal.**
- 7. To improve efficiency, the smaller the surface area of a file engaged in the canal, the greater the rotation speed should be.**
- 8. The more spirals a flute has per unit length around the shaft of a ground file, the less resistance to torsion deformation there is, but the more flexible the file is.**
- 9. The fewer spirals a flute has per unit length around the shaft of a ground file, the more it resists torsion deformation, but the more rigid it is.**
- 10. The sharper the cutting blade of a file, the fewer spirals per unit length the file should have.**
- 11. The greater the number of flutes with similar helix angles, the greater tendency a file has to screw into the canal and become bound.**
- 12. Maximum engagement of a file occurs when it progresses into the canal at a rate that is equal to its feed rate, the rate the file progresses into the canal without the application of positive or negative pressure.**
- 13. Less canal transportation occurs with a file having greater flexibility, an asymmetrical cross-section design, and/or a land.**

Section II.

Mastering Instrument Designs

18. How do we test designs?

To test the validity of claims for file designs, a computerized clinical simulator was constructed to simultaneously measure torque, pressure and time, during the prescribed use of instruments, to determine efficiency and the threat of file failure. The simulator computer provides the means for precisely duplicating motions (US Robotics) designed to simulate clinical applications for comparing different instruments. While eliminating operator variability and conforming to operation recommendations, computer programming can control the preparation parameters for the depth and the speed of file insertion and withdrawal, as well as the speed of file rotation. Not only can the stress of the force of insertion and torsion of each individual file size and taper be measured under different circumstances, but also the stresses, using different file sequences, can be recorded in order to determine the least stressful and most expeditious technique approaches. All measurements are plotted over time to illustrate when and how stress occurs.

Rather than measuring the over-all flexibility of the file, the simulator device can be used to measure dynamic flexibility, recording the resistance to bending as a rotating file progresses onto an inclined plane or simulated curved canal. The measurement occurs over time as different diameters and cross-section configurations of the file transverse a curvature.

The logged data help determine the methods for which each instrument may be used most effectively while minimizing the threat of failure. The simulations can be applied to different anatomies and technique solutions quickly become apparent, rather than having to rely on subjective and time-consuming trial and error experience that lack the benefit of controls. An examination of the results puts the manufacturer's technique recommendations in perspective, validating or invalidating their claims. Identifying technique enhancements and file design improvements become more feasible. The results can be used to substantially enhance efficiency and may be surprisingly different from what has been recommended.

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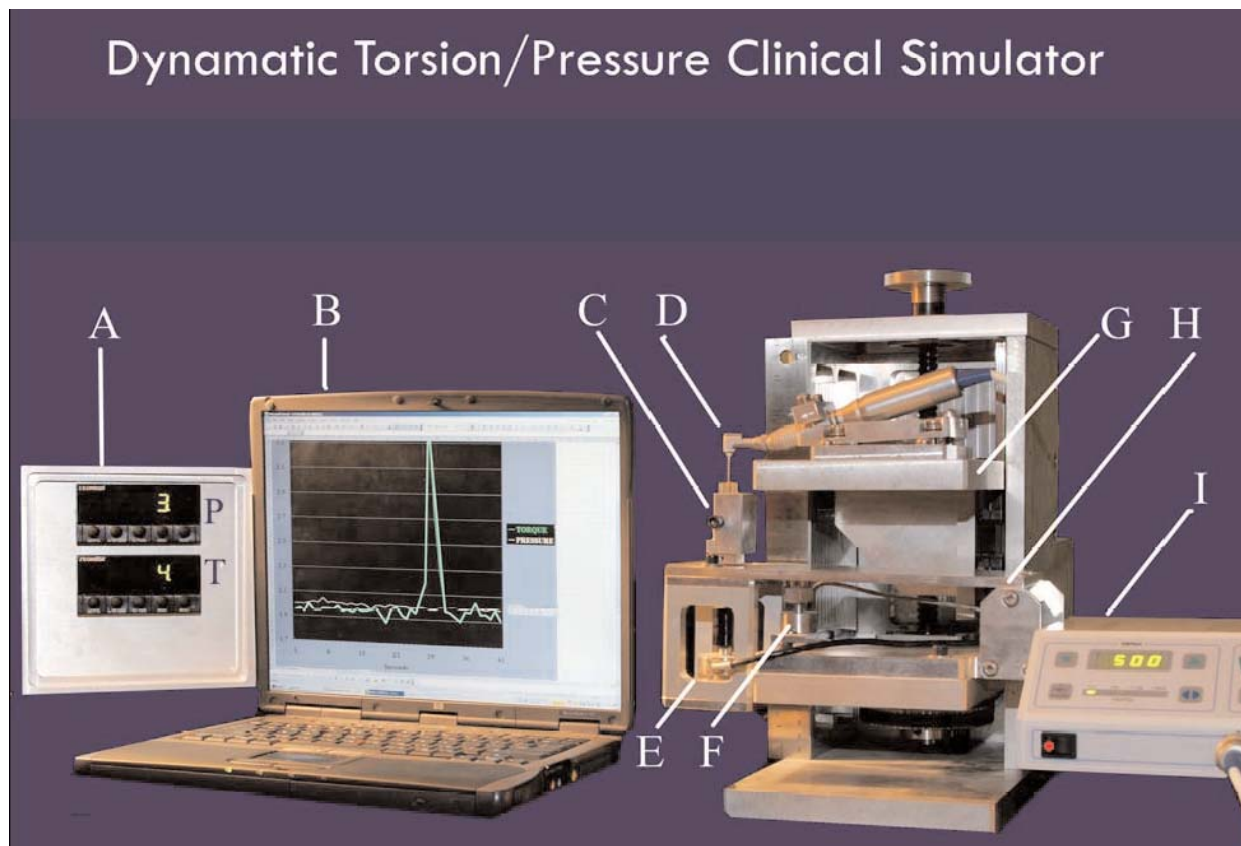


Fig. 42 The clinical simulator computer (B) includes two software programs. One program executes the motions of the rotary handpiece and the other is fully integrated with the hardware for the custom acquisition of data. The desired rotation speed of the file is adjusted by the handpiece control box (I). The handpiece is mounted on a stage (G) that is raised and lowered at rates and distances determined by the parameters of the particular program used to precisely reproduce selected clinical insertion-withdrawal movements of the rotating endodontic file. The file is inserted-withdrawn into, or from, a root canal or plastic practice block mounted on a bracket (C). The bracket is supported by a hinged stage (H) that is free to travel in the same plane as the file to simulate the clinician's resistance to any screwing-in forces that might result from the rotation of the file. The torsion exerted by the rotating file is measured by a torque transducer (E) and the pressure is measured by a pressure transducer (F). The pressure and torque are simultaneously viewed on a screen display (A). The resulting measurements in real time are based on graphical programming (B).

The most important information afforded by the simulator is not the means to just avoid breakage, but to minimize stress on the file, data that can distance the clinician from the possibility of failure while maximizing

efficiency. Although the simulator can facilitate the formulation of technique design, it does not eliminate the need to understand the causes of file failure and the means for avoiding it.

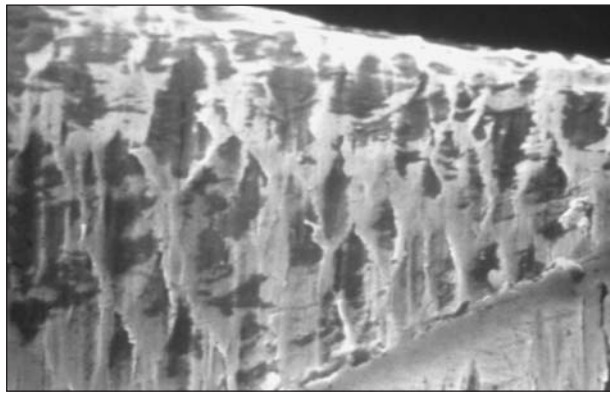
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19. What causes breakage?

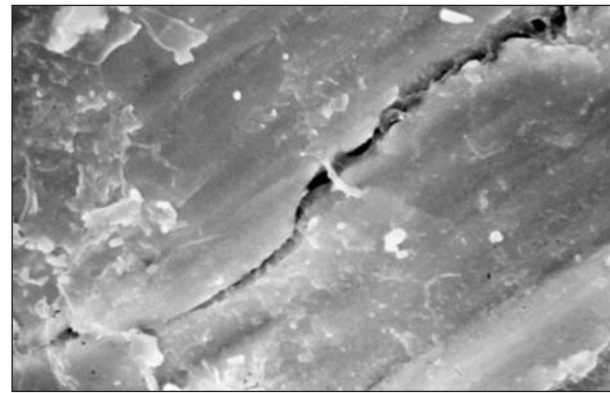
In the most basic terms, the strength of a file is due to the cohesive forces between atoms. As forces that tend to deform a file are increasingly applied, the forces to separate atoms increase and their attractions decrease. Breakage occurs when the force of separation of the atoms exceeds the force of attraction.

On a larger scale, the molecules of a metal are arranged in patterns denoting its crystalline structure or grain, and the fracture of files usually can be characterized in

two ways. 1. One cause of fracture is accompanied by an apparent deformation of a file and the separation occurs as a result of *slippage between the planes* of its crystalline boundaries, most often due to the excessive forces of **torsion**. 2. Another fracture may occur *across the grain* of the metal with little or no apparent deformation. This type of fracture can be seen as a result of **fatigue** most often caused from the excessive stresses of the repetitive compression and tension that occurs during rotation of a file around a curvature. Of course, most fractures are a *combination* of different forces of separation.

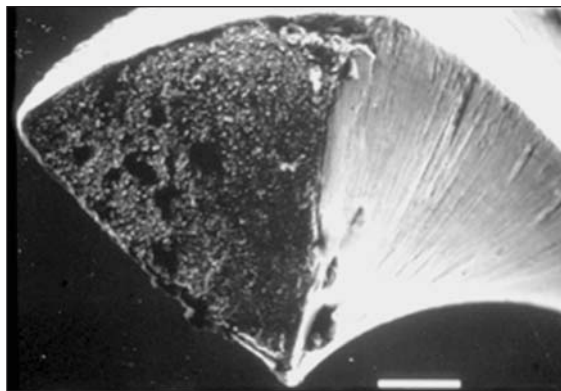


A

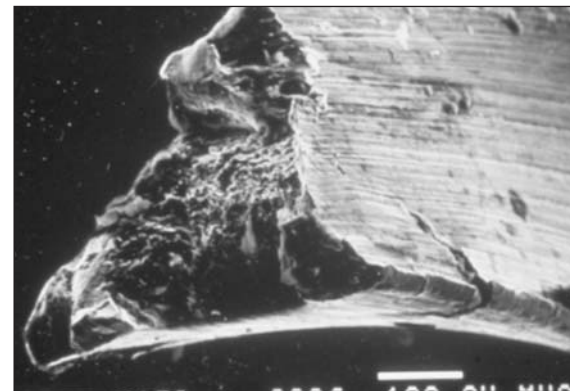


B

Fig. 43 Irregularities in the surface of the leading edge of a file shown in image (A) act as stress concentration points for potential torque or fatigue failure. The force to propagate the crack, shown in image (B), can be less than one half the amount of force that was required to form it. Examining the SEM images of the quality of manufacturing can provide valuable information for the probability for breakage.



C



D

Fig. 44 The fracture across the grain of the metal of file (C) was probably the result of fatigue. Note the faults along the blade that are particularly susceptible to stress concentration. The fracture resulting from slippage between the crystalline boundaries in file (D) was probably the result of excessive twisting.

20. What is torsion?

Torsion is the axial force of being twisted when one part of a file rotates at a different rate than another part. Any distortion of a file that results from twisting, such as un-winding, is caused by stress of torsion. When a file resists rotation during hand instrumentation with conventional .02 tapered files, excessive torque can usually be tactilely perceived and file breakage can usually be avoided. On the other hand, even the use of torque limiting handpieces during rotary instrumentation does not provide the means for adjusting to varying circumstances, such as curvatures, the amount of file engagement, nor the diameters of the file that are engaged. Any excessive torque, as a result of these circumstances, is not always avoided by preset torque limitations. On the other hand, the torque limits can be set so low that file failure would be difficult, but effective canal enlargement would also be limited. Understanding the factors that cause

excessive torque is the most reliable means for avoiding torsion failure.

21. What causes torsion stress?

Torsion stress on a file is primarily the result of: (1) the force of cutting, specifically, how effectively a chip is formed and deflected from the wall of the canal, (2) the force of screwing-in due to the spiraled blades that become engaged in the wall of the canal without deflecting the chips that are formed, (3) the force of abrasion of the non-cutting surface of the file against the wall of the canal, (4) the force of distortion resulting from rotating in curvatures, and (5) the force the debris exerts on the wall of the canal as it accumulates in the flutes. Incorporating designs to reduce any of these forces increases the file's efficiency and is one approach to advance instrument design. Another approach is to provide designs that can accommodate greater forces, although the efficiency may remain unchanged.

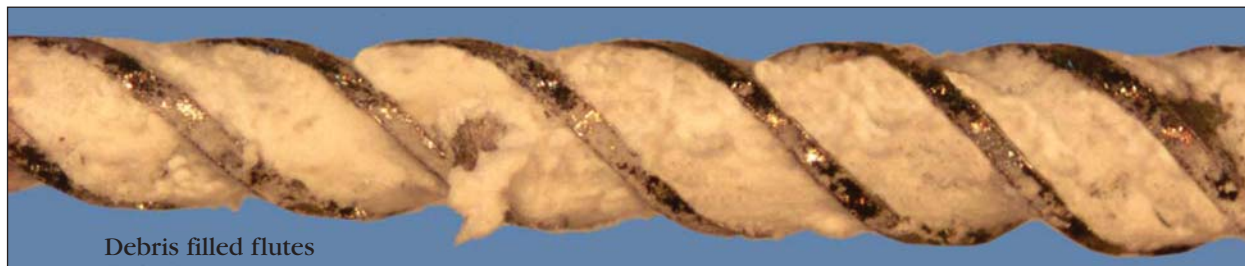


Fig. 45 Abrasion of rotating accumulated debris against the canal wall increases torsion stress. The file efficiency is decreased when the debris prevents the cutting edge from engaging the canal wall. Limiting file engagement by using different file tapers, restricting the depth of file insertion, and frequent irrigation can minimize debris accumulation.

A file with a larger diameter can resist more torsion stress than one with a smaller diameter. The relationship varies very closely with the square of the file radius. Therefore, a size .25 mm diameter can resist as much as 50% more torque than a size .20 mm diameter having the same design, even though the difference in diameters is only .05 mm. The reason that the description direct relation between torque and radius squared is not used, is because the complicated variables in the crystalline structure of nickel titanium cause variations in the patterns of breakage.

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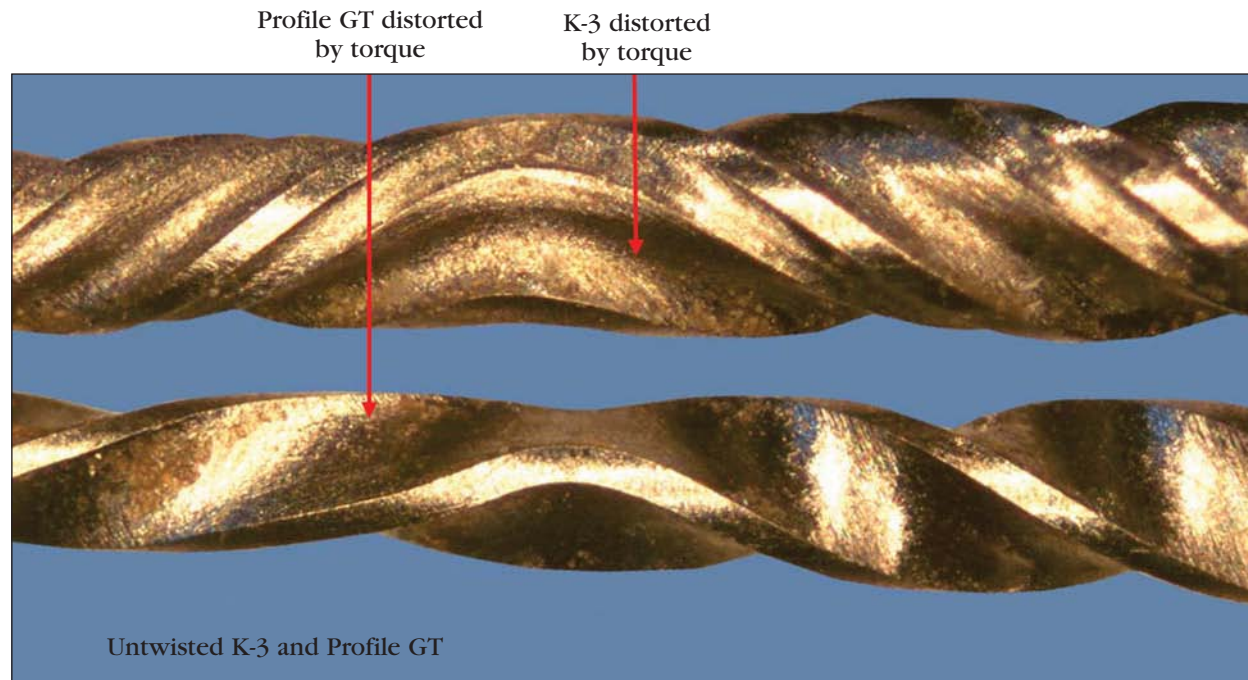


Fig. 46 Stainless steel has an effective modulus greater than that of Nickel Titanium (Table 5). The significant advantage of NiTi is its flexibility. Although NiTi's super-elastic ability to be distorted without permanent deformation is often cited as an attribute, this quality is of little consequence for a file rotating over 200 rpm. Some NiTi files may continue to twist for three complete revolutions after becoming bound in the canal without failing, compared to less than one revolution for stainless steel files, but without warning, this may mean less than one second of reaction time for the operator. A more meaningful relationship may be the torsion force required to fracture the file relative to its flexibility. Most files having the same size and taper usually distort in similar manners, however the force for distortion varies with file design.

22. How do torque requirements vary with the file diameters that we are likely to encounter in canals?

Smaller diameters of files are more likely to break with the application of torsion. However, binding of a small diameter can usually be detected and prevented if that part of the instrument that is likely to become bound is the only part that is engaged in the canal. When the difference between the largest and smallest diameters engaged is minimal, increases in torque are usually the result of increased applied pressure. **If the torque and pressure required for rotating the larger diameter portion of a file exceeds the torque required to break the**

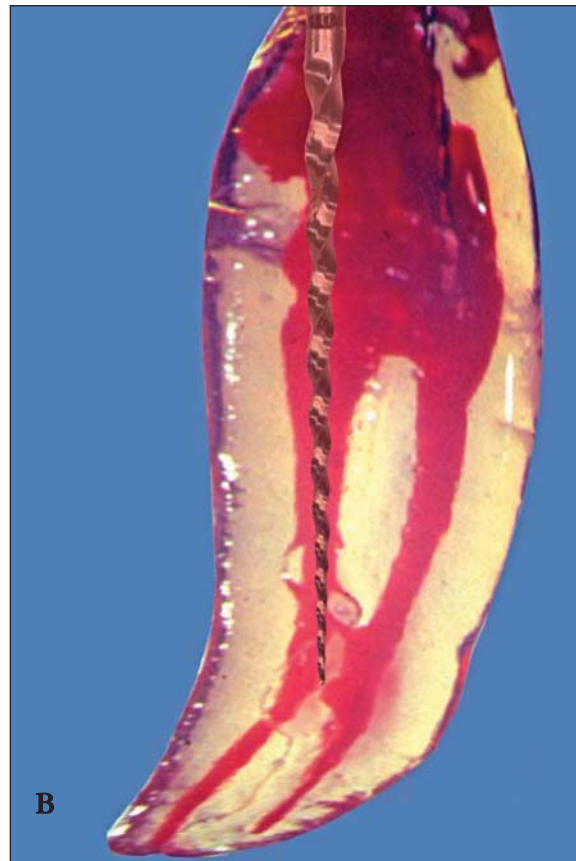
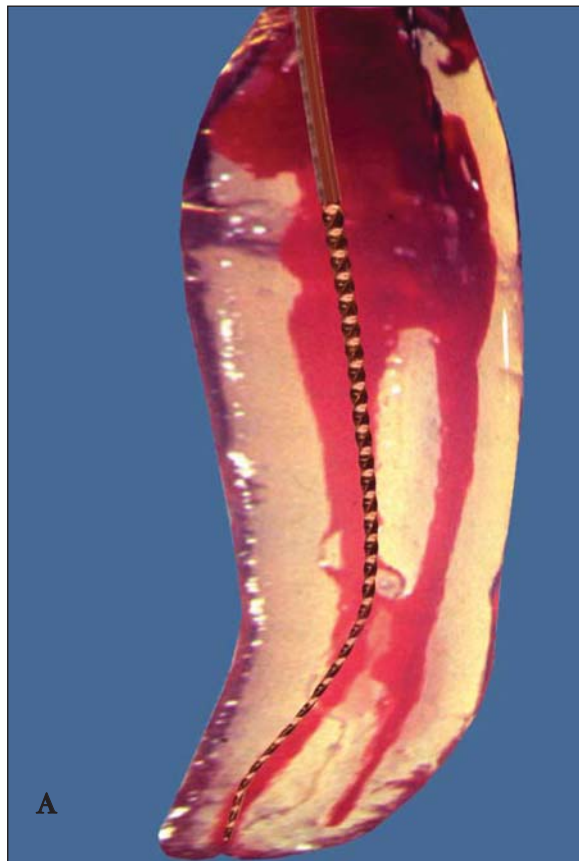
smaller diameter portion, the file is particularly vulnerable when engaging the larger diameter since the stress on the smaller diameter cannot be detected.

Even establishing **glide paths** (canals or segments of canals enlarged to a diameter larger than the tip of a subsequent file to allow its passive entrance into that portion of the canal) is no assurance that a small tip size cannot be unknowingly pushed into, and become bound in, canal aberrations such as a fin, an anastomosis, a bifurcation, or auxiliary canal while the force necessary for engaging the larger diameter is applied. Glide paths are usually established with smaller more flexible files that follow the pathways of least resistance, usually that portion of the canal having the largest diameter

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along its path. As larger tapered, less flexible files that have smaller tip sizes than the established glide path are used, the files can have a tendency to deviate from the glide path and can become bound in the smaller

canal aberrations. The file that is most likely to follow the canal is one that remains 360 degrees engaged, but that is assuming it has adequate flexibility and excessive torsion is avoided.



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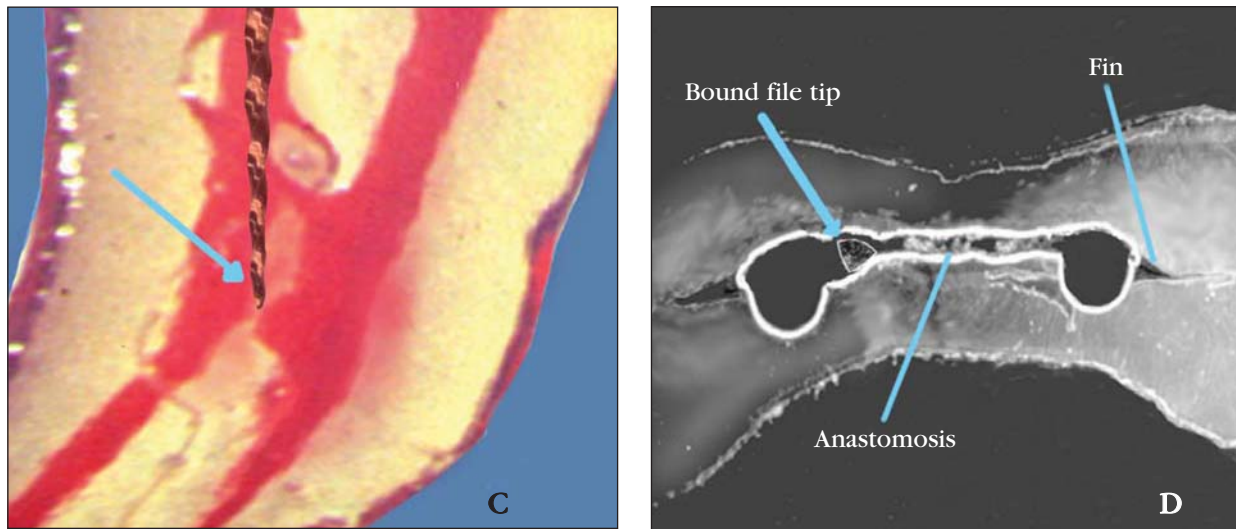


Fig. 47 A glide path, a minimally enlarged pathway for subsequent files to follow (A), is established with a small flexible file. However, as a larger tapered file with small tip size (B) is used, its greater rigidity can force its tip into a fin or anastomosis in a curvature (C & D) and can become bound. The torque required for the larger diameter part of the file to function could be sufficient to cause the bound tip to separate.

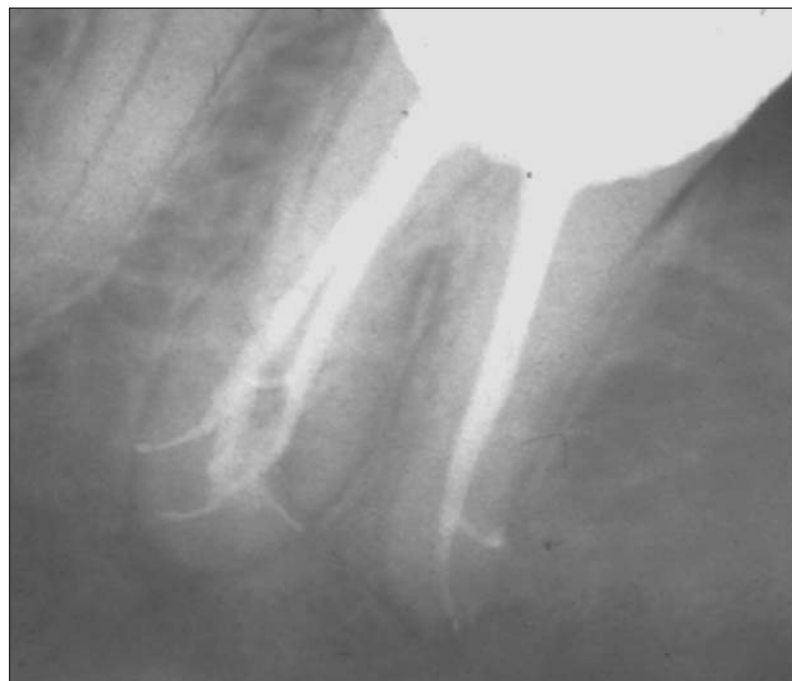


Fig. 48

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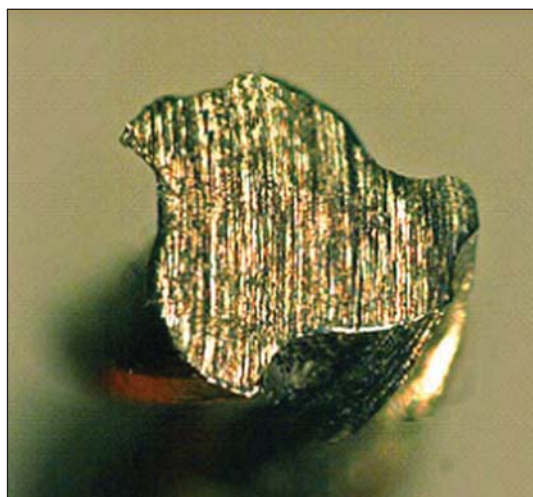
Establishing a pathway might not preclude a file of a different size and taper from following a different path than expected. The result can be a tip that becomes bound when the necessary torque and pressure is applied for a larger diameter and taper to function. The example (above) illustrates several aberrations of the canal system in which a small file tip could have become bound.

23. Can different type files having the same diameter have different abilities to withstand torsion?

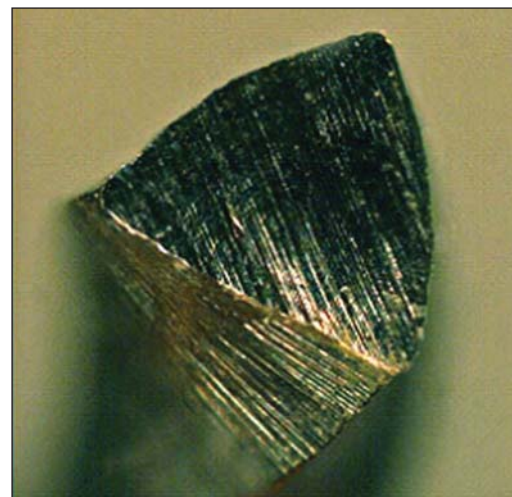
The ability of a file to resist torsion failure depends on the **file's diameter, cross-section mass and design**. Files having the same basic design and same diameter can have a different cross-section mass or central core by having different depths of flutes. In which case, the file having the greatest cross-sectional mass will be able to withstand the greatest torsion.

The design of the instrument plays an important role in resisting torsion. For

instance, a cross-section design that incorporates angular notches may be more susceptible to torsion failure than designs that incorporate more gradual curvatures. Abrupt changes in the continuity of the straight lines of design can result in **stress concentration points** or areas of weakness when stress is applied. However, cross-section designs having more stress concentration points and less cross-section mass can actually have more resistance to the torsion stress that is required to function if the shape is carefully designed to resist the forces of torsion and by incorporating more efficient designs.



K-3 cross-section



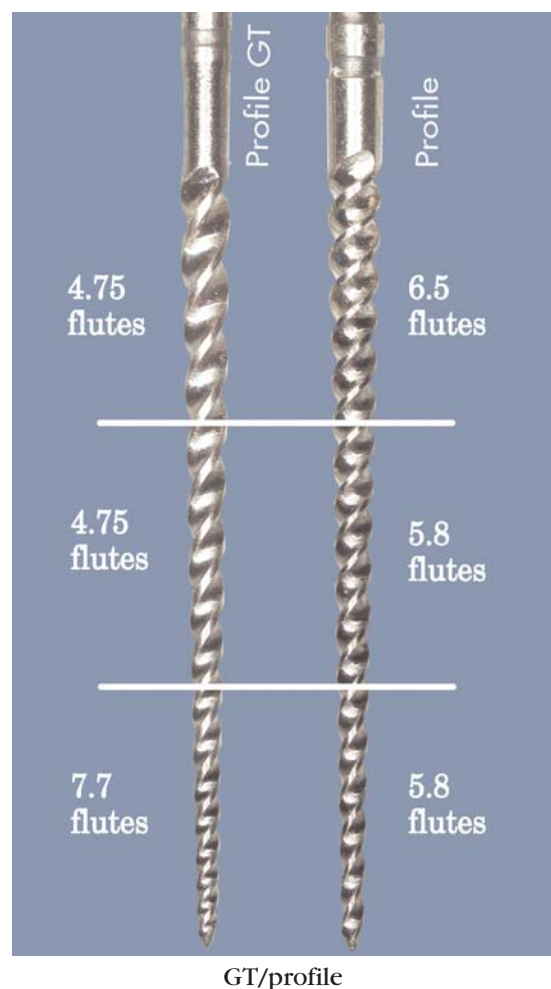
ProTaper cross-section

Fig. 49 Although the ProTaper file and the K-3 file may have a similar cross-section mass at a particular diameter, the K-3 file is significantly more efficient in its cross-section design cutting ability.

An important consideration is the **efficiency** of different designs. Some files that might require the same torque to fail as other files, might also require less torque during its ideal operation for enlarging the canal, and therefore, have fewer propensities for breakage. As an example, the K-3 file has a cross-section mass similar to the ProTaper file and has greater deviations from straight lines of design. Yet, it can enlarge the canal with less torsion stress.

Files having the same diameter and cross-section design, such as the Profile and Profile GT, can have different resistances to torsion failure along their working lengths because of the differences in the number of spirals per unit length. Generally, the file with ground flutes and more **spirals** will have greater flexibility, but less resistance to torsion failure. However, if twisting forms the spirals, as is the case with most stainless steel and prototype nickel titanium files, the metal can become work-hardened and have greater resistance to torsion failure.

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24. What does testing tell us about safe torque?

Although devising formulae for calculating the safety that would include all the uses for which a file might be subjected in varying canal anatomies is impractical, testing the following technique protocols and limits for abuse can provide valuable information for preventing file failure. Ideally, the following formula would be considered:

Safety Torque Quotient = Peak Torque at Failure ÷ Peak Torque for Use

A safety torque quotient of less than one would indicate that a technique is relatively safe. Failure is more likely to occur once this ratio is greater than one. The peak torque is easily determined. The file is bound at its tip and rotated until it separates while recording the torque required for rotation. Once the maximum torque to failure is determined, technique parameters can be established to provide guidelines to avoid exceeding that torque. The data acquired with the clinical simulator testing can indicate the probability for file breakage for particular technique recommendations. If the probability for file breakage is unacceptably high, the technique recommendations could be re-examined to determine if altering the technique could reduce stress.

The following is an example of determining the "Safety Torque Quotient" of a technique: A 35/.04 Profile failed when it was inserted into and extended an additional two millimeters a canal prepared to a size 40/.04. The torque (Peak Torque for Use) recorded at failure was 539.5 g-cm. The Peak Torque at Failure recorded for a rotating 35/.04 Profile with a bound tip was 145.8 g-cm. Applying the Safety Torque Quotient formula, $539.5/145.8 = 3.7$, the quotient indicates that the operational torque is 3.7 times the torque required to break the tip. This quotient can be expressed as the file's **Safety Ratio**. Any quotient (Safety Ratio) that equals more than one indicates that failure is likely if the tip should become bound.

However, determining the torque that could be used as a standard would not be an easy matter, because recommended techniques vary. The torque established during

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one technique would not be valid for another. However, comparing the torque required for the largest diameter to function to the torque required to break its tip can certainly

ly provide an indication of the file's propensity for breakage if its largest diameter is engaged and its smallest diameter becomes bound.

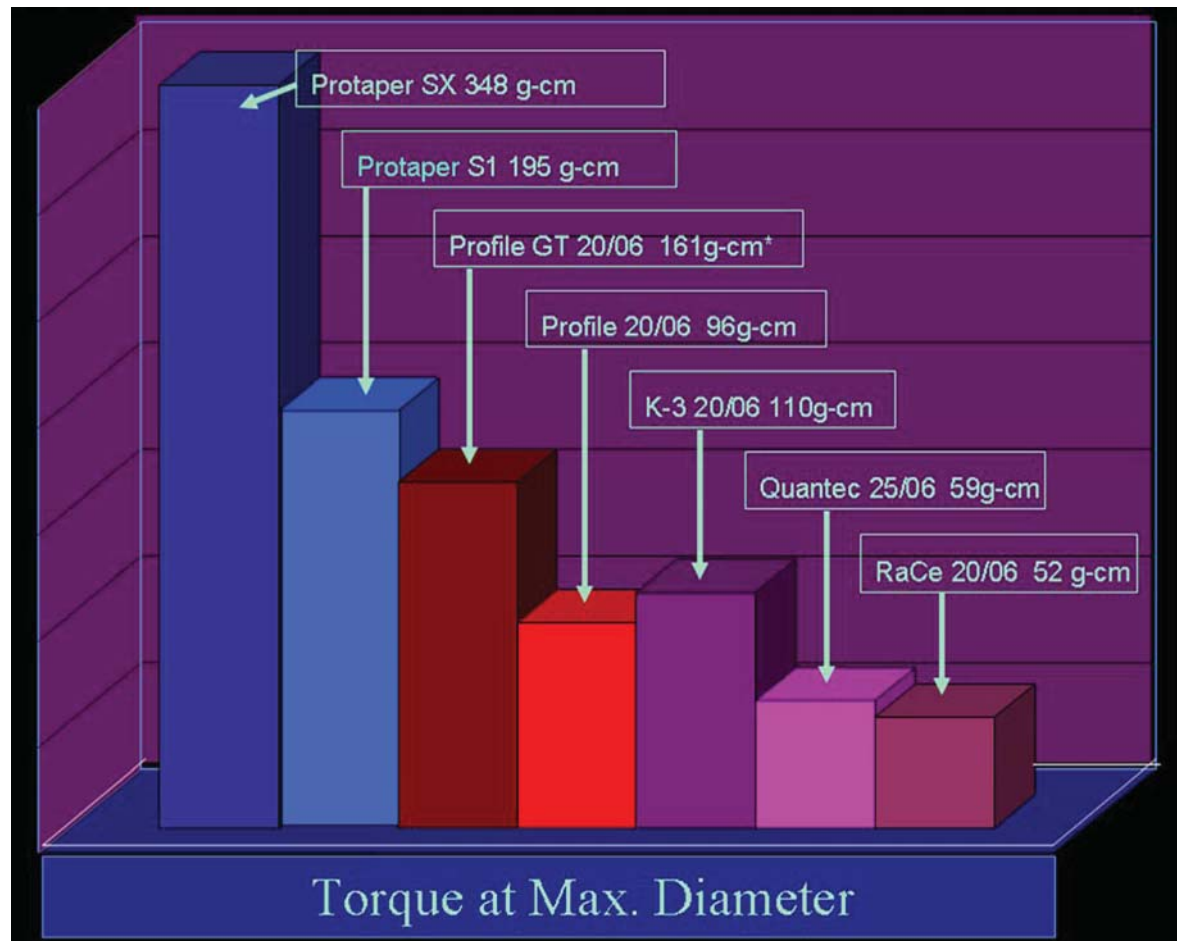


Chart 50 Each file rotating at 300 rpm was introduced into a canal in a section of plastic and advanced at a rate of 1 mm per second. The canal was 4 mm long and had a constant .70 mm diameter (illustration A, opposite page). With the exception of the Profile GT and the RaCe file, all files were carried to its 1.19 mm diameter and its corresponding maximum torque was measured and recorded. The Profile GT was carried to its 1.00 mm maximum diameter and the RaCe was carried to its .73 mm maximum diameter. These smaller diameters account for the lower recorded torques for the Profile GT and RaCe files.

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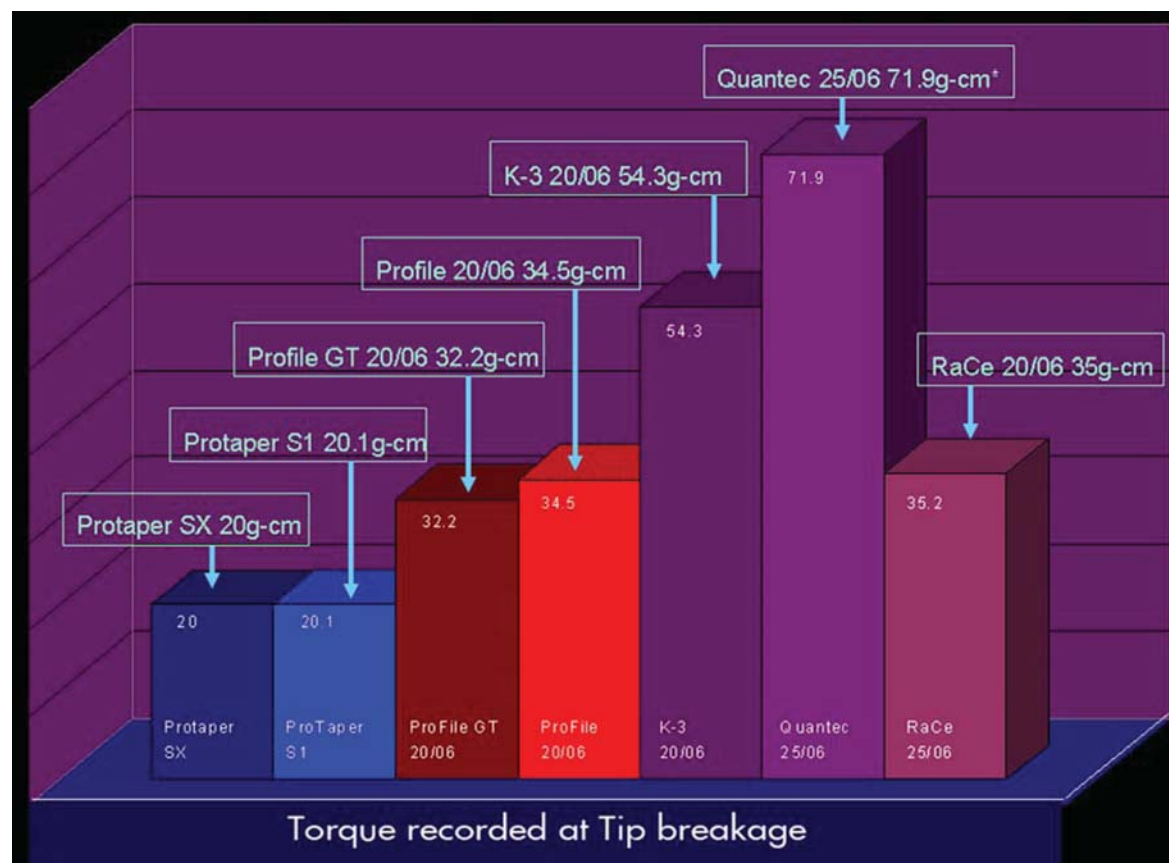
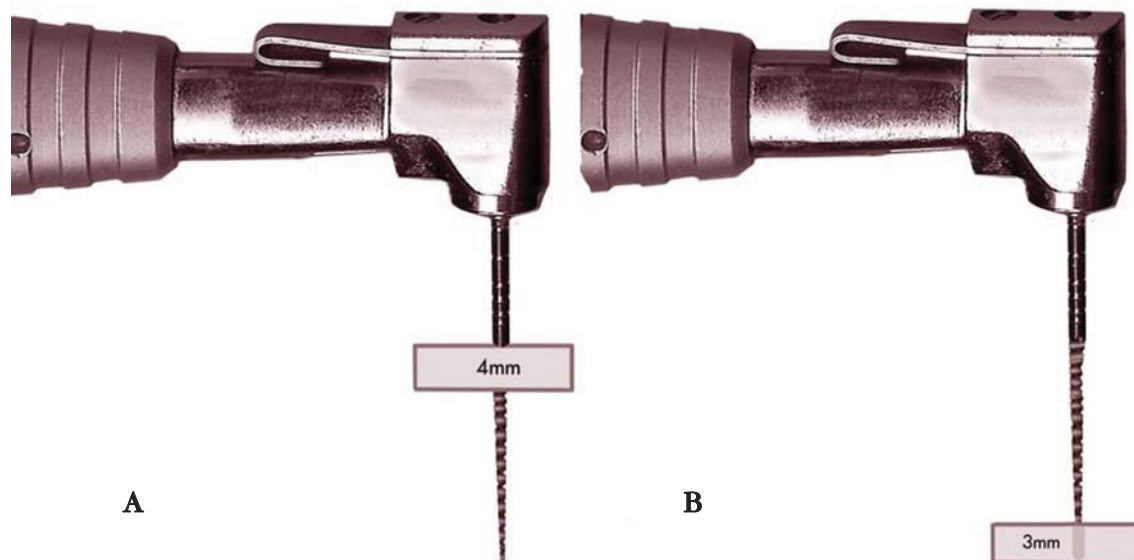


Chart 51 Each file was cemented at its tip with epoxy in a metal tube 3mm long. The tube was stabilized and the handle of the file was rotated at 1/2 rotation per second until the file fractured (illustration B, below). The maximum torque generated during the process was record.



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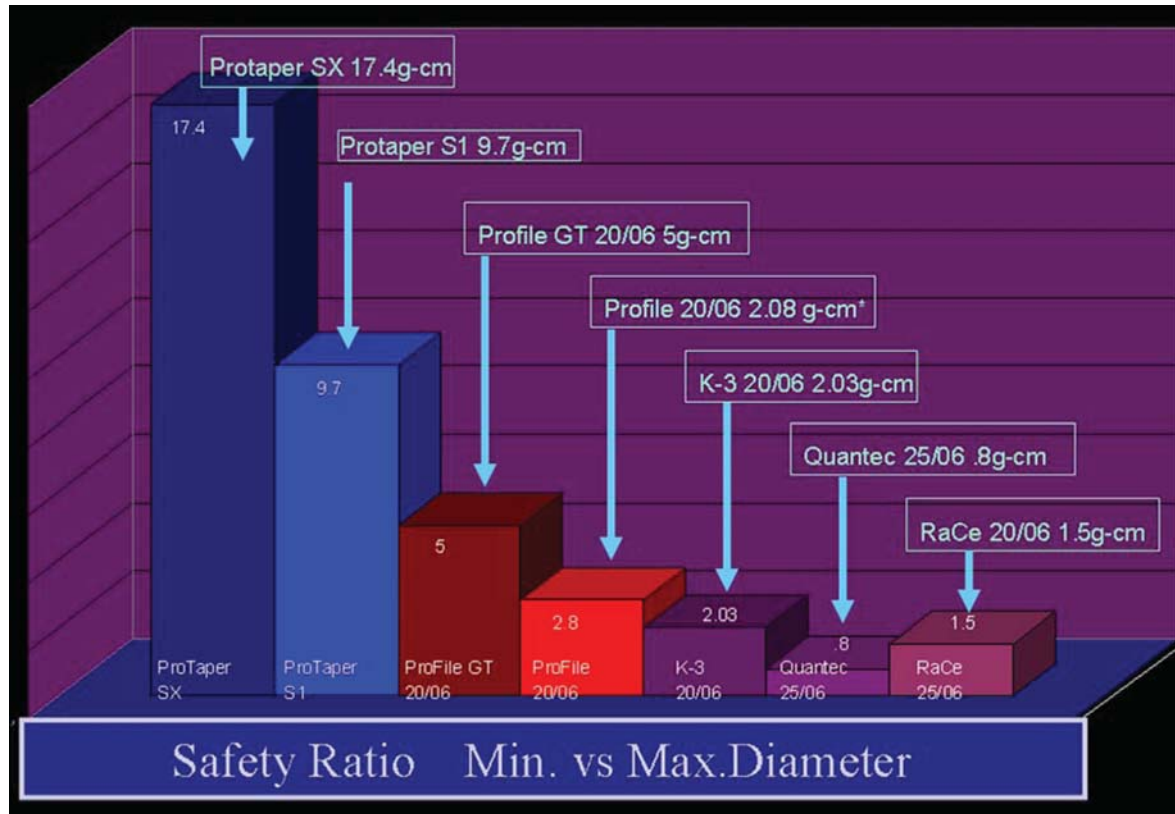


Chart 52 By dividing the torque recorded for tip breakage into the torque generated for enlarging a canal at its maximum diameter, the resulting ratio provides an indication of the safety of binding the file's tip while enlarging the canal with the file's maximum diameter. Note that the torque required for enlarging the canal at the file's maximum diameter can be 17 times that is required to break its tip if it should become bound, a ratio of 17:1.

The introduction of handpieces with “torque control” has been an attempt to compensate for poor safety ratios and decrease undesirable results. A torque limiting handpiece can be a valuable adjunct if the torque settings are not arbitrary, but actually reflect the torque a particular file should not exceed during a particular operation. The torque adjustment should depend on the diameters and the length of the file engaged as well as the canal anatomy. Important to remember, while using a torque limiting handpiece, is the fact that torque is not the only factor to consider in avoiding problems during canal preparation. For example, if a small file is inserted into the preparation of a larger file,

only the tip initially engages while extending the preparation. With only the tip engaged, little torque might be generated, but the tip can encounter an abrupt curvature or a constriction that offers resistance. If greater pressure is exerted on the file, the torque might not increase appreciably, but ledging can occur or the tip might become bound and low torque breakage can be the result. Interpretation of variations in pressure is an integral part of instrumentation techniques. Any time greater pressure must be applied in order to make additional progress into the canal, terminating the use of that instrument and using a file of a different taper can reduce the threat of failure. An instrument of a smaller size and

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taper could be used beyond this point of resistance and another file of a larger size and taper could be used short of this point if the safety ratio is to be minimized.

25. Does irrigation reduce torque requirements?

Irrigation and lubrication can reduce torque requirements by as much as 400% compared to rotating in a dry canal. However, shorter strokes of insertion can be more effective than carrying the rotating file to greater depths into the canal with fewer insertions, even with irrigation. The percentage of the file engaging dentin plays an important role in influencing the torque reduction resulting from lubrication or clearing of debris by irrigation. When the rotating file becomes engaged for more than a few millimeters, the interface of irrigation is reduced between

the surface of the canal and the file. This has little effect in reducing torsion, since any irrigation has little opportunity to penetrate the additional distance with the file due to the rotating file moving the irrigating solution in a coronal direction. This is especially the case when the irrigation is intermittent rather than constant and the insertion of the file is continuous rather than being done in shorter strokes. The use of a handpiece, having a tubular connection with an irrigation pump, can be beneficial even with a short stroke technique, not so much for lubricity, but for the elimination of debris before its accumulation contributes to resistance of rotation.

Evidence suggests a surface treatment of files and irrigation can have a synergistic effect in reducing torsion. By providing lubricity, surface treatment of the files can decrease the torque required in order to rotate nickel

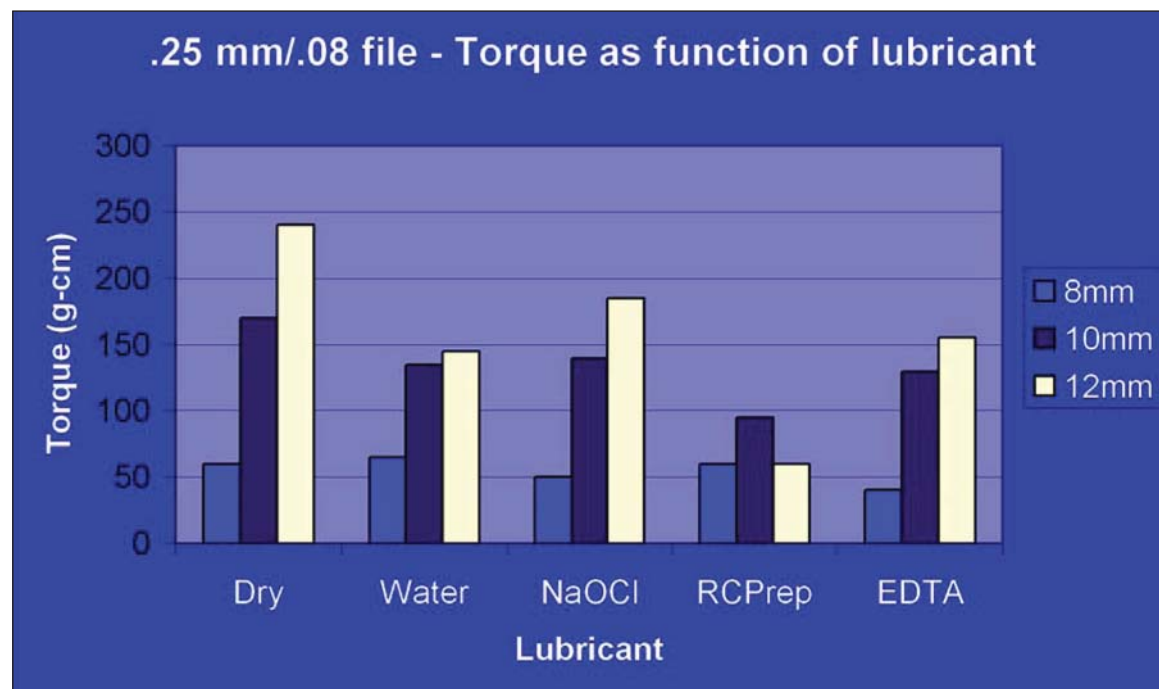


Chart 53 The importance of engagement is illustrated. Quantec files were inserted in 1 mm increments at 1 mm/s to a depth of 8 mm, 10 mm and 12 mm. The torque recorded is an average of 6 files taken for each depth. Note minimum engagement can have approximately the same benefit as irrigation in reducing torque.

titanium files substantially without diminishing cutting ability. Surface treatments on stainless steel files have been demonstrated to reduce torsion forces by as much as 600% and may render stainless steel files to be a more desirable alternative to nickel titanium files in situations where little flexibility is required. A recent development of coating files with an amorphous diamond-like surface may become available for enhancing the lubricity and providing a harder surface.

One can see from the above chart that it is important to know how much the file will become engaged with each millimeter of insertion and with each change of instrument size or taper. Many are surprised to learn that one millimeter of insertion can result in 15 millimeters of engagement in which case, irrigation would have little benefit in reducing torsion (see Fig. 108).

26. How important is file flexibility?

Successful endodontic treatment requires considerable knowledge of root canal anatomy and instrument limitations. The current literature is replete in illustrating that the root canal system rarely has straight cylindrical canals, but rather has frequent complex curvatures and aberrations. The phenomenal benefits, particularly the flexibility, of rotary nickel titanium files for negotiating difficult anatomies, while enhancing the quality of canal enlargement and debridement, can prove invaluable and outweigh most risks encountered during canal preparation.

The rotation of flexible instruments around curvatures can certainly facilitate one's ability to accomplish a 360-degree canal enlargement while maintaining the central axis of the canal and preserving more tooth

structure. Although canal curvatures in the mesial-distal plane may be apparent on radiographic examination, the severity of curvatures, due to angulations and location in the facial-lingual plane, may not be so apparent. In this case, when there is a lack of awareness, flexibility is often an unseen benefit.

On the other hand, most dentists resort to stainless steel files when using the smallest sizes for establishing the working length and the patency of the apical foramen. Having the flexibility needed but lacking the toughness (the ability to accommodate the sudden application of stress and strain) of nickel titanium, these smaller sizes of stainless steel files are used manually and have the advantage of being easily pre-bent without excessive stress in order to negotiate curvatures. Bending a nickel titanium file can be accomplished, however, its property of shape memory causes the file to return to its original shape unless unusual force is used. Although shape memory provides the advantage of the file resuming its straight shape after being used, this property offers no advantage in the canal unless one is attempting to straighten the canal.

One must keep in mind that continuous rotation of even flexible instruments can eventually lead to cyclic fatigue failure. The rotation of larger diameter instruments that lack adequate flexibility, may often be the cause of treatment complications, due to canal transportation or instrument breakage, when other factors receive the blame. The frequency of curvatures in each plane of tooth anatomies dictates that we should assume their presence. Understanding the limitations of flexibility, or the lack of it, and the complexities of anatomies, is essential for maximizing the benefits of rotary instrumentation.

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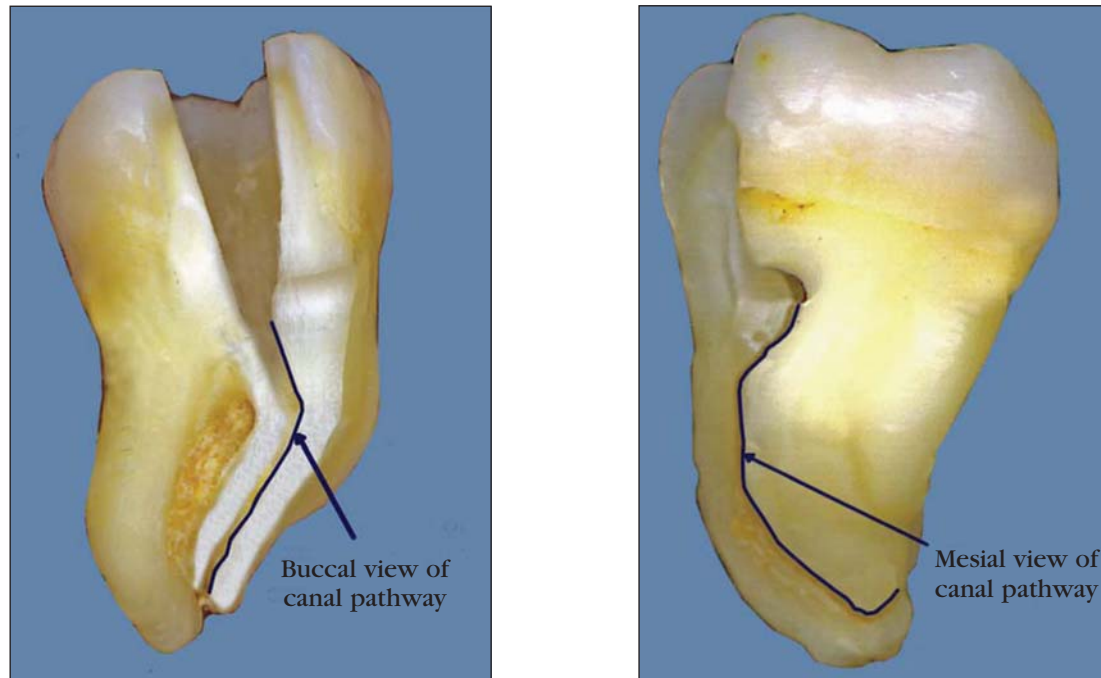


Fig. 54 Tooth structure has been removed to expose and outline the pathway of the mesial-buccal canal. Note that the buccal view gives no indication of the buccal-lingual curvature and especially its abrupt curvature at the apex.

27. What is fatigue?

File fatigue is the result of any repetitive stress that occurs, predominantly during flexion, while rotating around a canal curvature and is closely related to the square of the file's diameter. A file can withstand more stress during a single rotation around a curvature than it can after numerous rotations. Metal fatigue usually begins at minute defects on the file's surface or at stress concentration points in the design that result in the formation of stress cracks. Since substantially less stress may be required to propagate a crack than is required for its formation, a fatigue failure is particularly insidious and can occur without any obvious warning. Any prediction of fatigue failure is complicated by stresses that result from geometrical discontinuities, porosities, inclusions, and overheating that occurred during manufacturing.

Knowledge of the relationships of file sizes and canal anatomy is especially important when dealing with the combined stresses of torque and fatigue. Computerized handpieces are being developed to address the problems of fatigue as well as torque, but the judgments for determining appropriate technique should always be the role of the dentist, and mechanical technology should not be an excuse for a lack of understanding.

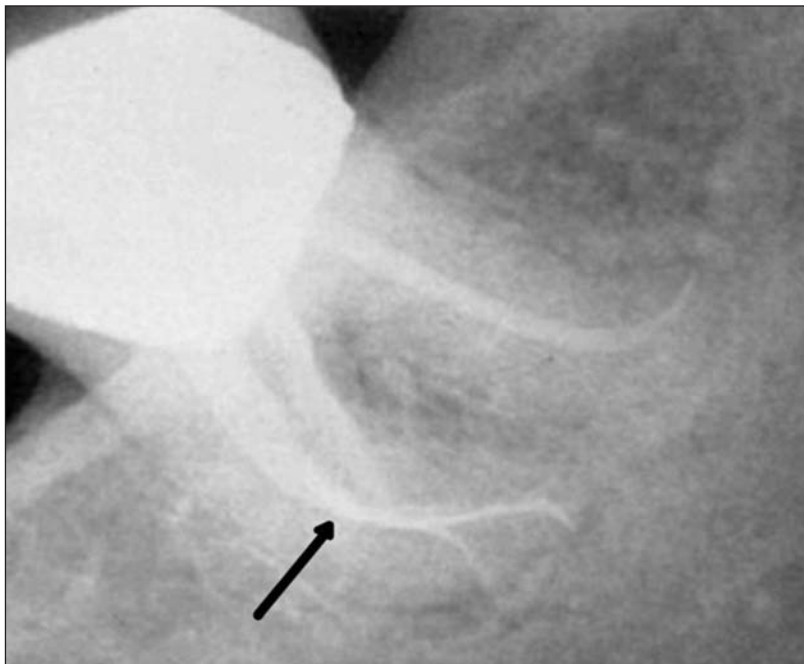
28. What causes fatigue?

On the inside of the curvature of a canal, a rotating file is compressed. On the outside of the curvature, the file undergoes tension. During continuous rotation around a curvature, each surface of the file undergoes compression and tension until faults in the file begin to spread and the file fatigues. Generally, the greater the distance between

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the stress of tension and the stress of compression, the greater the total stress on the instrument is. The smaller the diameter of a file, the longer it can rotate around a curvature without fatigue failure. The file's resistance to fatigue has a close inverse relationship with the square of the file radius. Therefore, a size .20 mm diameter resists fatigue approximately 50% more than a size .25 mm diameter even though the difference in the diameters is only .05 mm. As the diameter of a tapered file becomes greater, while progressing through a curvature, the stress on the file eventually reaches the point of potential failure and the use of the file

should be terminated in favor of a smaller diameter or smaller tapered file. It is important to point out that the taper, as well as the diameter, also plays an important role in determining the file's resistance to fatigue. The stress is concentrated over a shorter distance of a file with a larger taper and the propensity for fatigue increases. Hence, coronal curvatures can certainly be more challenging when attempting to instrument to the root apex, especially while using larger tapers and sizes. The dentist must consider the number of rotations, the file diameter, the file taper, the file design, and the degree of curvature in order to determine how to avoid fatigue.



Larger tapered files commonly used in minor mid-root or coronal curvatures have diameters that can cause severe compression and tension stresses that can lead to fatigue failure. The file diameter at the point of curvature and the number of file rotations are important considerations during canal instrumentation.

Fig. 55

Courtesy of Dr. William Watson Wichita, KS

The pressure at the more flexible tip end of a file will result in substantially more bending than at the more rigid larger diameter handle end. As a file progresses into a curved canal, the diameter that transverses curvatures increases and the file's resistance to fatigue failure decreases. *Therefore, the length of a file that extends beyond a curvature becomes a very important consideration and one that is ignored in many recommended instrumentation techniques.*

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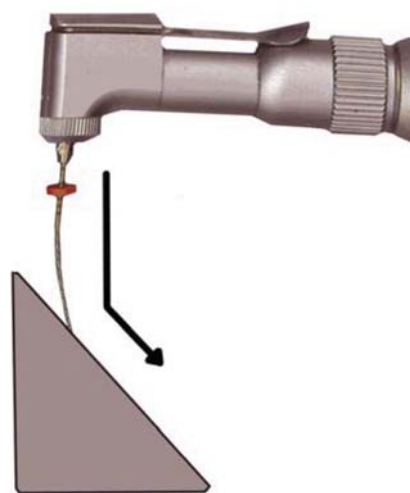
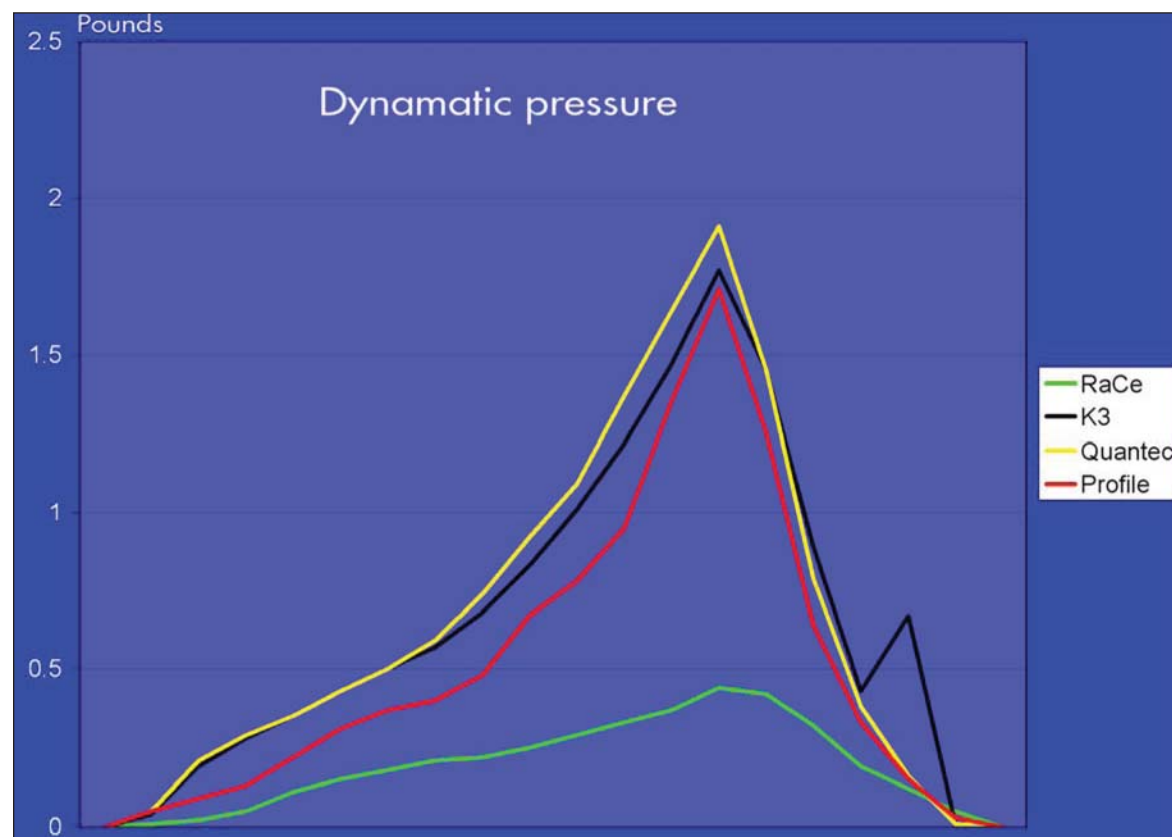


Fig.56

Rotating at 300 rpm, each 25/.06 file progressed onto a 45 degree inclined plane with an open canal, the file's resistance to deflection or the force exerted on the incline was measured. The resulting measurements plotted each file's flexibility as increasing diameters of the file was deflected. The RaCe file's greater flexibility is due to less cross-section area and its unique design of incorporating spiraled and non-spiraled segments along its working surface. However, most of the deflection occurs at specific areas of stress concentration points rather than being more evenly distributed over the length of the working surface. Note the flexibility of the RaCe file.

29. What is the relationship of the resistance to fatigue and flexibility?

Generally, the file that is more flexible is also more resistant to fatigue. This is certainly true of files having the same or similar designs. However, as with resistance to torsion failure, resistance to fatigue is dependent not only on diameter and mass, but also on design and quality of manufacturing. The RaCe file has considerably more flexibility than the other files of the same size tested and on the basis of having less cross-section area would be expected to be more resistant to cyclic fatigue. However, the flexibility is not evenly distributed over the full length of the file, but has intermittent specific areas of greater flexibility at stress concentration

points. Instrument design appears to have the particular importance with greater amounts of deflection. Although testing illustrating no significance difference of cyclic fatigue of the RaCe file as compared with other files of the same size and taper with moderate deflections is discussed later in this chapter, a study measuring cyclic fatigue with greater deflection demonstrated the RaCe file significantly less resistance to cyclic fatigue compared to Profiles and K-3 files (James, H.Y., Schwartz, S.A., Beeson, T.J., *Cyclic Fatigue of Three Types of Rotary Nickel-Titanium Files in a Dynamic Model. Journal of Endodontics 32:1 Jan.2006.*). Important to remember is the fact that these stress concentration areas are also more susceptible to torsion failure.

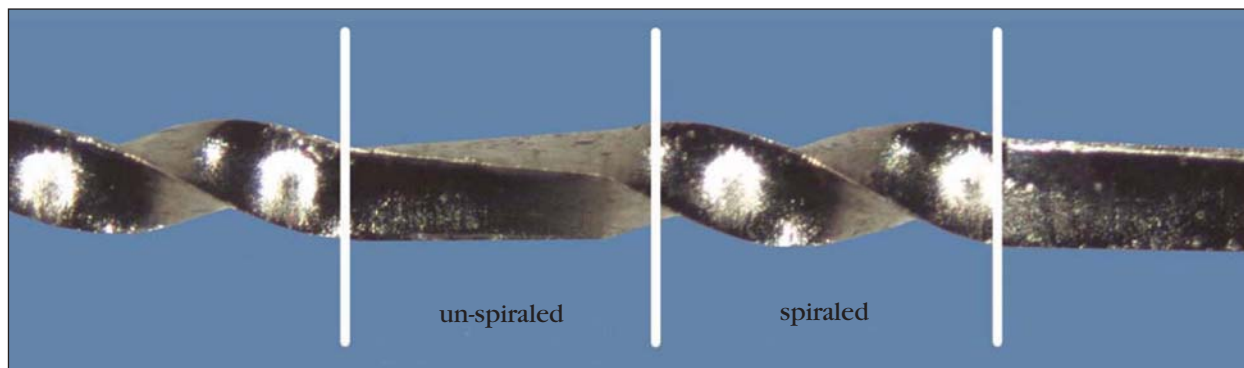


Fig. 57 The spiraled and non-spiraled segments incorporated in the RaCe design and its smaller cross-sectional mass results in high flexibility. The configuration of the RaCe file offers a unique opportunity to study the different stress characteristics of its spiraled and non-spiraled segments along its working surface.

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Fig. 58 Note that essentially all bending occurs at the junction of the spiraled and non-spiraled segments where stress concentration also occurs. Since flexion is confined to the spiraled portion of the working area rather than being distributed more evenly over the entire area, fatigue will occur more quickly. The recommended speed of 500 RPM is another factor that increases fatigue. On the other hand, the torsion generated by the RaCe file is substantially less than most files because of the reduced tendency for screwing in due to the spiraled and non-spiraled configuration.

The original Lightspeed file design was comprised of a short working portion followed by a reduced diameter shaft similar to a Gates Glidden drill and had the greatest flexibility of all the files tested. A greater resistance to fatigue would be expected to accompany its flexibility when only the small diameter dimensions of its round shaft are considered. However, testing resulted in significantly shorter rotation times, when rotated at the manufacturer's recommended speeds in curved

canals, when compared to other files having comparable tip sizes but larger working surface diameters. One contributing factor was the rotation speed of approximately 2,000 rpm, recommended because of the minimum engagement of the working surface. A more plausible explanation might relate to the manufacturing process, which results in circumferential scoring around the shaft of the file that act as stress concentration points for potential failure.

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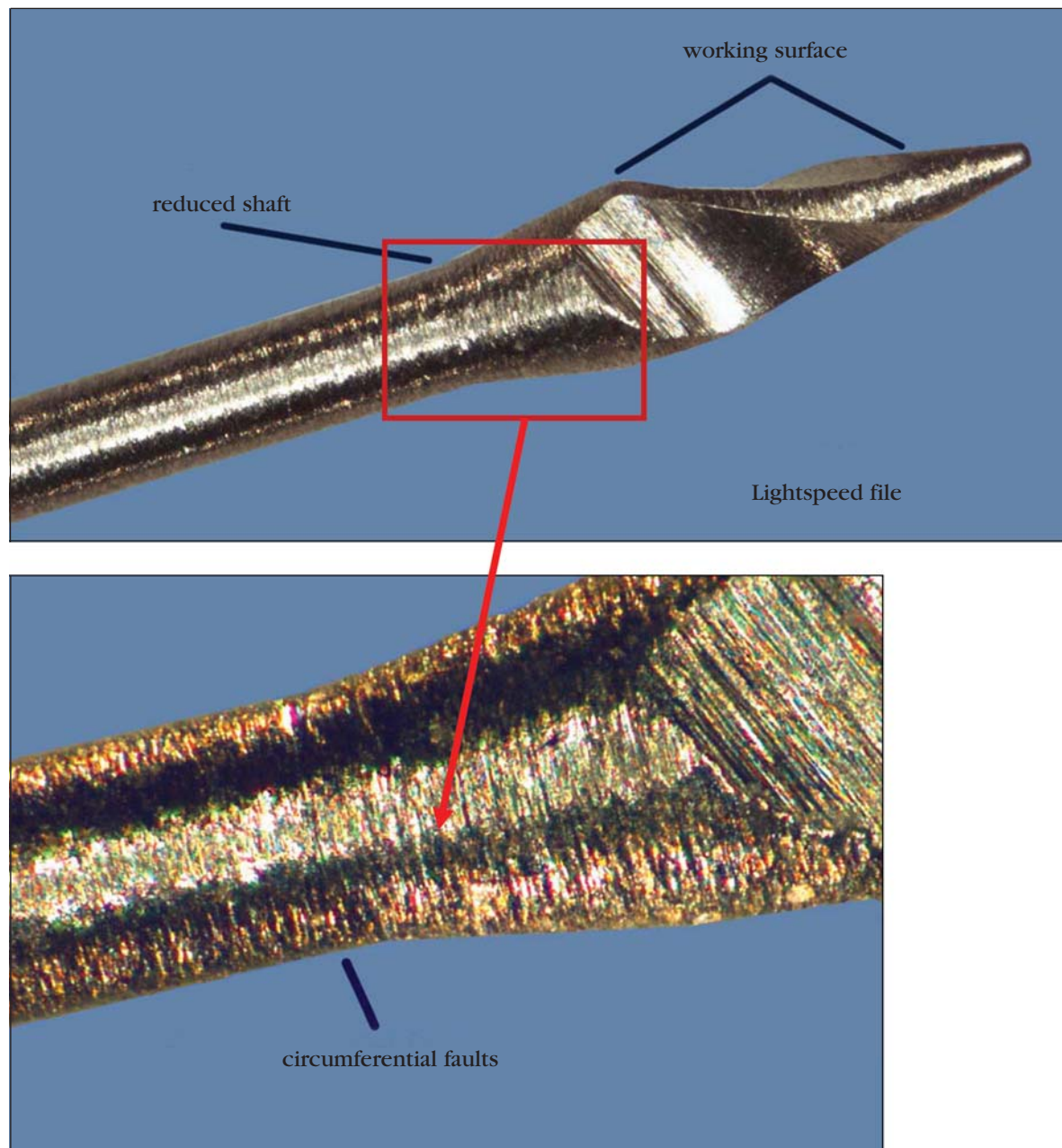


Fig. 59 Fatigue is primarily the result of the propagation of faults. Unlike other files, the faults of the original Lightspeed file design completely circumscribed its reduced shaft. The compression and tensile forces could act on the circumferential faults to accelerate failure.

Whereas torsion failure is more vulnerable to stress concentration points in the transverse cross-section design, fatigue is more dependent upon stress concentration points in the longitudinal cross-section. For instance, even though the core mass, total

mass, and diameter may be the same for a Hedstrom file and a conventional K-type file, the Hedstrom file has more abrupt changes in lines of design in transverse and longitudinal cross-sections that cause it to more likely fatigue.

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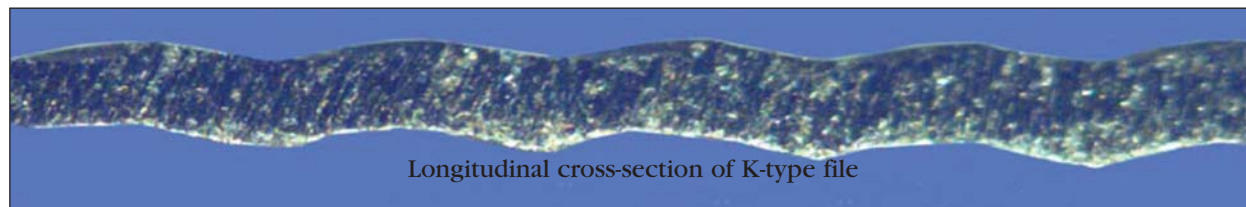


Fig. 60 Longitudinal cross-section of a **K-type** file. Abrupt changes in the lines of design are minimal.

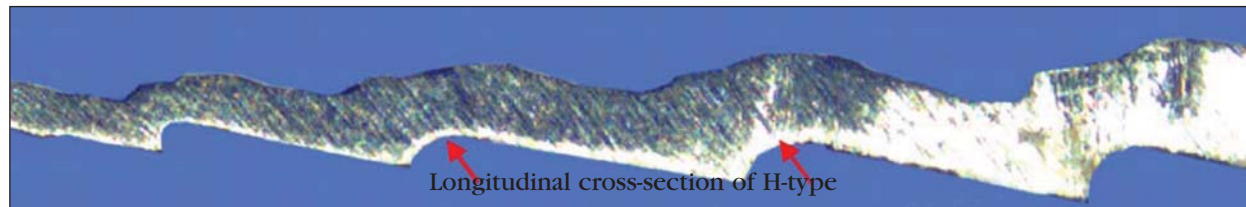
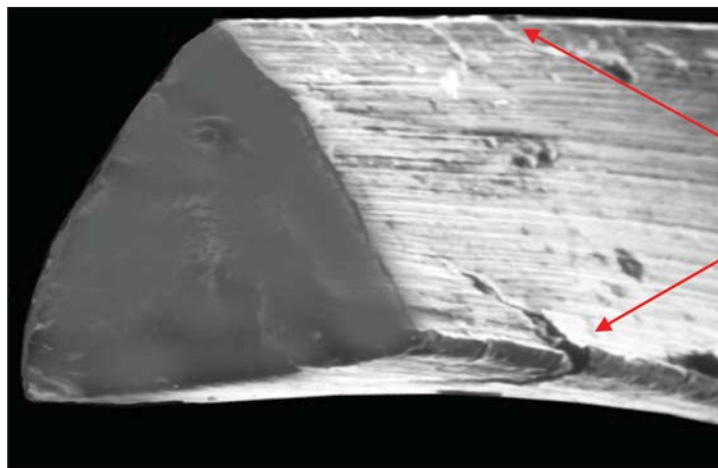


Fig. 61 Longitudinal cross-section of **H-type** file. The stress concentration points (red arrows) are more severe than those of K-type files when viewed in longitudinal cross-section.

The shape of the file at its circumference also determines a file's resistance to fatigue. In basic terms, the resistance to separation of molecular attraction provided by a greater mass of a rounded surface following a file's cutting edge at its circumference, such as a

land, may be more resistant than an angular circumferential surface, i.e., a triangular cross-section in which the smallest surface mass is subjected to the greatest tension, but the prediction of failure becomes more difficult to compute.



An angular surface at the radial extremity of the file has unsupported defects that can lead to failure with less tension than a leading edge supported by the axial surface of a land.

Fig. 62

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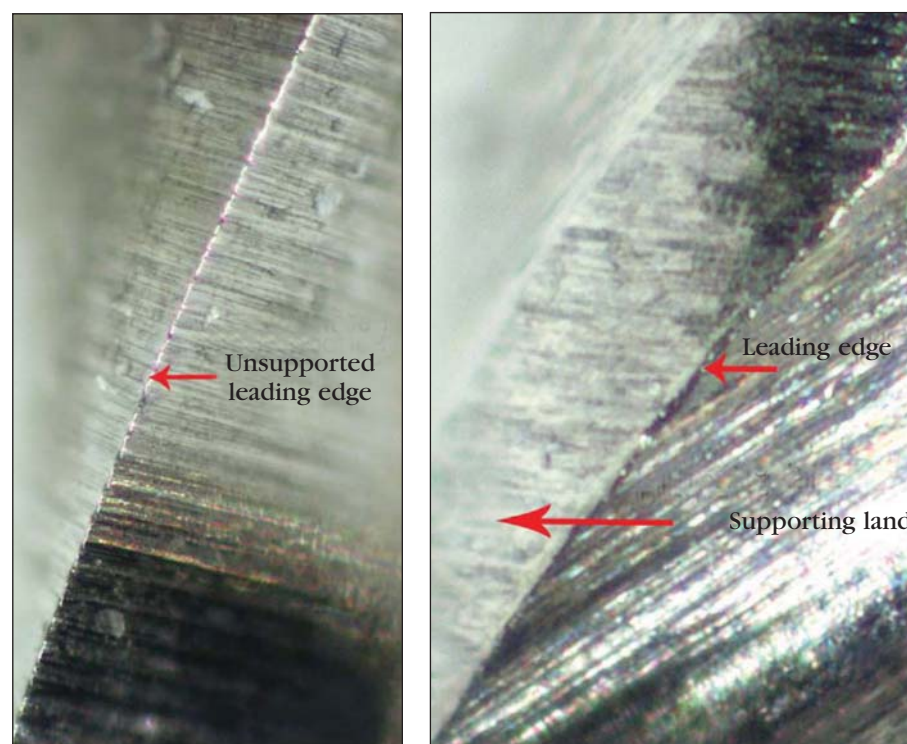


Fig. 63

30. How can files of the same diameter have different flexibilities?

Two of the most common means of increasing file flexibility for ground nickel titanium files is to decrease the cross-section area by increasing the **depth of flutes** or to increase the **number of spirals** of the flute per unit length. Either change, however, can alter the file's characteristics and increase its susceptibility to torsion failure. For instance, increasing the number of spirals increases the screwing-in tendencies of a file and causes greater torsion stress.

The fact that the Profile and the Profile GT instruments have the same size and taper as well as almost exactly the same cross-section design but different dimensions provides an excellent opportunity to examine the consequences of the differences. The Profile has

fewer spirals at the tip end that renders it slightly less flexible, less likely to become bound by screwing-in, and more resistant to torsion deformation. Although one would expect the Profile to generate more torque at its handle end due to the increased engagement area of more spirals during rotation than the Profile GT, its narrower lands enables it to enlarge the canal with less torque. The longer working surfaces of smaller Profile GTs allow a greater engagement of their total working length that can also cause greater requirements of torque during instrumentation.

The characteristics of file flexibility differ between instruments formed by twisting and grinding. As pointed out, more spirals in ground nickel titanium files result in greater flexibility. The increase results from more cuts across the crystalline grain of the metal

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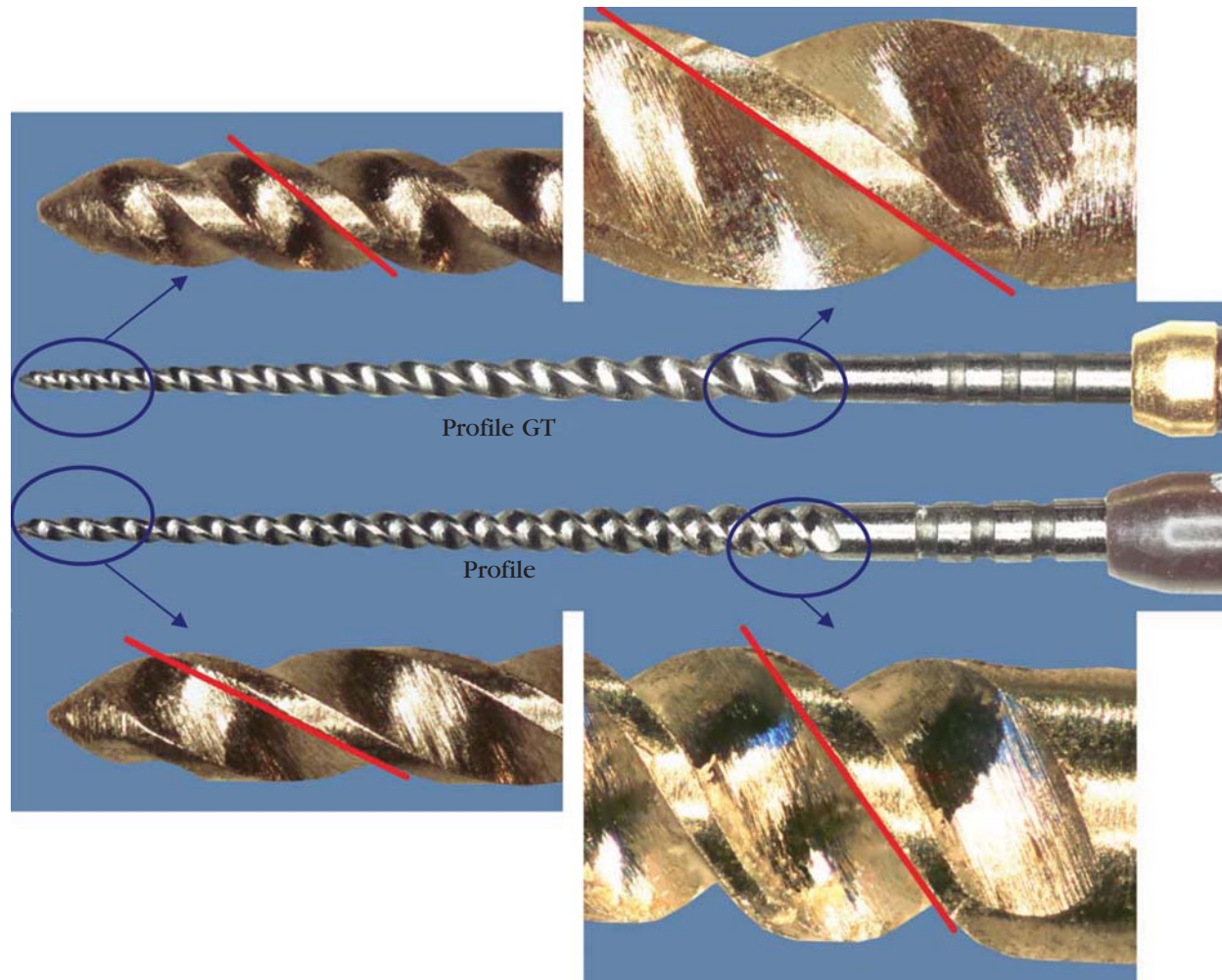


Fig. 64 Although the Profile GT 40/04 (top) and the Profile 40/04 (bottom) have nearly identical cross-section designs, there are important dimensional differences. The Profile GT has more spirals at the tip end and fewer spirals at the handle end. Note the differences of the angles of the leading edges of each at the tips and handle ends.

that also decreases its resistance to torsion failure. However, more spirals in stainless steel files formed by twisting result in greater resistance to deformation and less flexibility that is caused from the work hardening of twisting. Manufacturing by twisting may also result in added resistance to deformation in nickel titanium files if the problems of shape memory can be solved during the process. At this time no nickel titanium files are manufactured by twisting. However, advances in the ability to heat-set shape memory alloys

may provide the means for introducing this method of manufacturing as a competitive alternative to grinding.

How much flexibility a file design may exhibit at a specific point along its working surface may vary as it rotates in a curvature. The flexibility may be due to the file yielding to stress rather than accommodating it (exceeding the elastic limit), in which case failure can be the result. Deformation of the long axis or length of the file is not commonly apparent, since the file is rotating in the

curvature and any deformation is corrected as the file is rotated 180 degrees and becomes flexed in the opposite direction.

Dynamic testing, in addition to finite element modeling, becomes extremely important for determining what design modification constitutes an improvement. Characteristics of nickel titanium are not always predictable and enhancing one aspect of a file can compromise it in another. For instance, increasing the number of spirals decreases the file's resistance to torsion stress and increases the stress concentration points during flexion but generally increases its resistance to fatigue. One would expect increased flexibility with more spirals, but for flexibility to be accompanied with increased resistance to fatigue would be less certain.

31. What does testing tell us about avoiding file fatigue?

With the frequency of curvatures, we should assume their presence in a plane that is not apparent on radiographic examination. Only with very careful consideration of variations in the pressure required for progressing into the canal do we determine if curvatures are threatening file failure. One of the greatest problems in making that determination is the force required for rotating a large diameter file relative to the force necessary to progress through a curvature. Gauging the depth that the file can be inserted into the canal, before the file is rotated, can be especially helpful in determining the resistance due to curvature as opposed to the resistance caused by a constricted canal. Knowing the limitations of the file size and taper determined from testing, and their relationship to the canal anatomy, can definitely improve the ability to avoid file failures due to fatigue or torsion.

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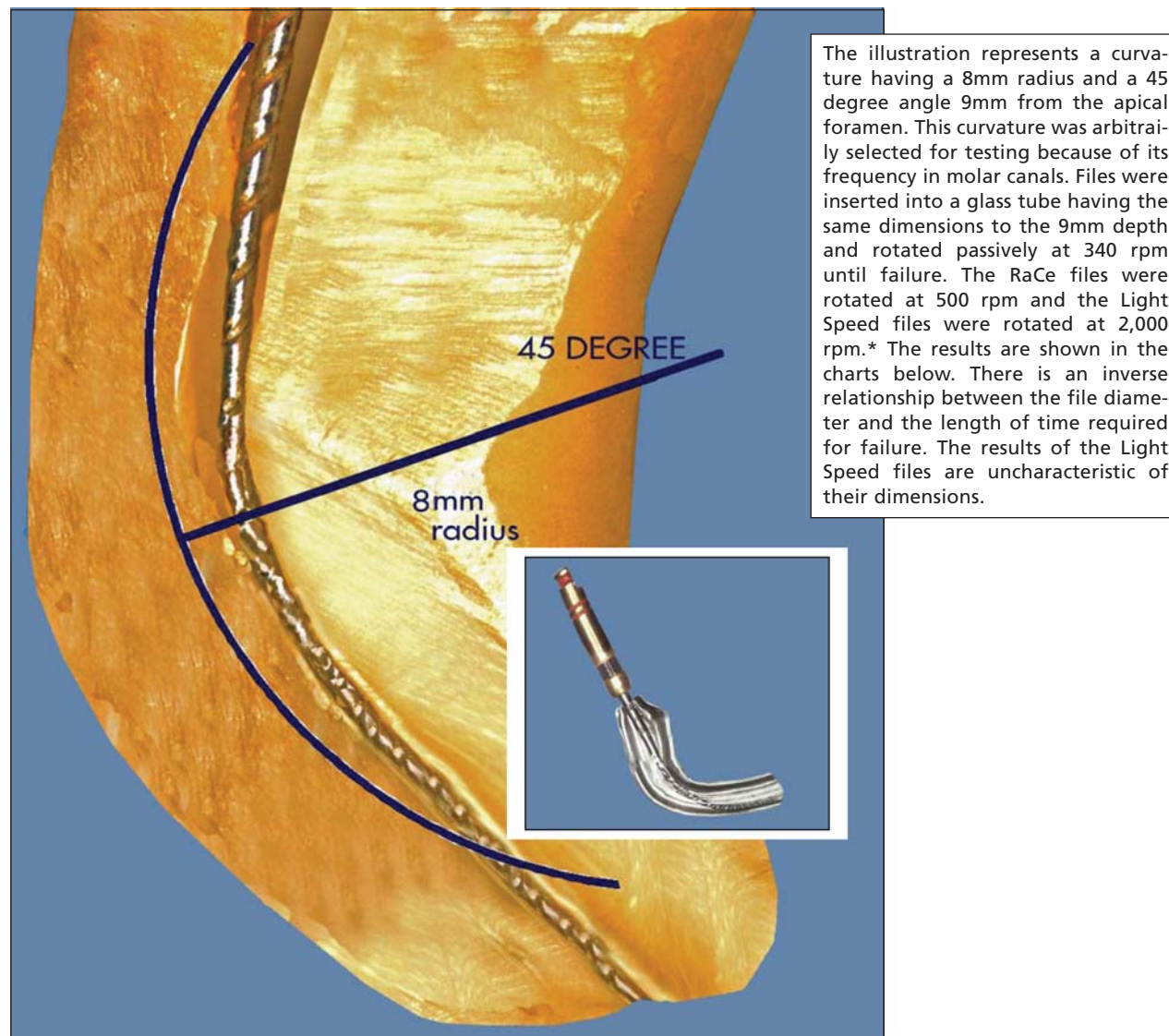


Fig. 64

Protaper S1—7s S2—5s F1—6s	Profile GT 20/04—50s 20/06—8s 30/06—5s	Profile 20/04—64s 20/06—12s 30/06—8s	K-3 20/04—62s 20/06—9s 25/06—7s
Quantec 25/04—25s 25/06—11s 35/02—160s	RaCe * 25/04—25s 25/06—8s 35/02—64s	Light Speed* 20—49s 30—14s 35—6s	

32. How can we determine the largest file diameter or taper that can be used in curvatures that we are likely to encounter?

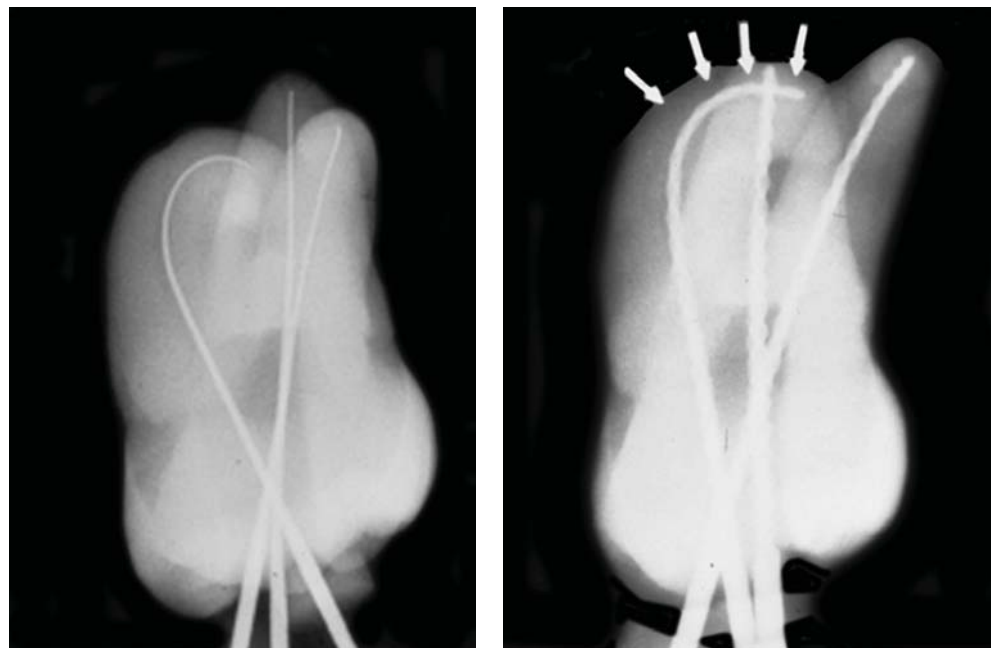


Fig. 65 As the file diameter increases as it progresses around a curvature, stress on the file increases and canal transportation is more likely to occur.

A severe curvature in the apical portion of the canal conceivably could be less threatening for file failure than a moderate curvature in the mid-root or coronal portion of the canal. When referring to the testing included in Section IV, one can conclude that negotiating curvatures of unknown severity but frequently encountered anatomies, should generally be approached with **particular caution if 360 degrees of a file's circumference is engaged and if the file dimensions**

at the point of curvature are greater than a size 60 for .02 tapers, a 55 for .04 tapers, a 50 for .06 tapers, or a 35 for .08 tapers. For instance, negotiating a curvature 4 mm from the apex with a 25/06 file would have a relatively rigid .49 mm diameter in the curvature and should be done with caution. File diameter selection and technique modifications become especially important in avoiding failure when considering the position and severity of curvatures.

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Maximum File Sizes requiring particular caution

The maximum file sizes for this anatomy that should not be exceeded while instrumenting to working length include: 1. Size 45/.02 taper 2. Size 30/.04 taper. None of the ProTaper files should be carried to length. Since the curvature is obviously greater than 45 degrees, smaller sizes should be used to minimize the threat of separation.

6 mm from apex

Fig. 66 A 90-degree curvature having a radius of 8 mm or less causes fatigue failure too quickly for instrumentation at the fulcrum of the curvature with file diameters .60 mm or more for .02 taper files or .55mm or more for .04 taper files. When the additional stress of torque is applied, the diameter size needs to be reduced.

If one would attempt to bend the largest diameter handle end of a 25/.02-taper file, it would be easy to imagine how quickly the .57 mm diameter at the handle end would fail in a curvature. The rigidity of this diameter would cause concern for canal transportation even if the file did not fail. A beneficial exercise to conceptualize flexibility and the force of the file against

the canal wall is to attempt to bend familiar diameters and tapers by hand to a 90-degree bend.

In addressing the potential for fatigue, file efficiency needs to be considered in addition to file diameter. Since efficient files require fewer rotations and less time to enlarge a canal, they can accomplish preparation with less fatigue.

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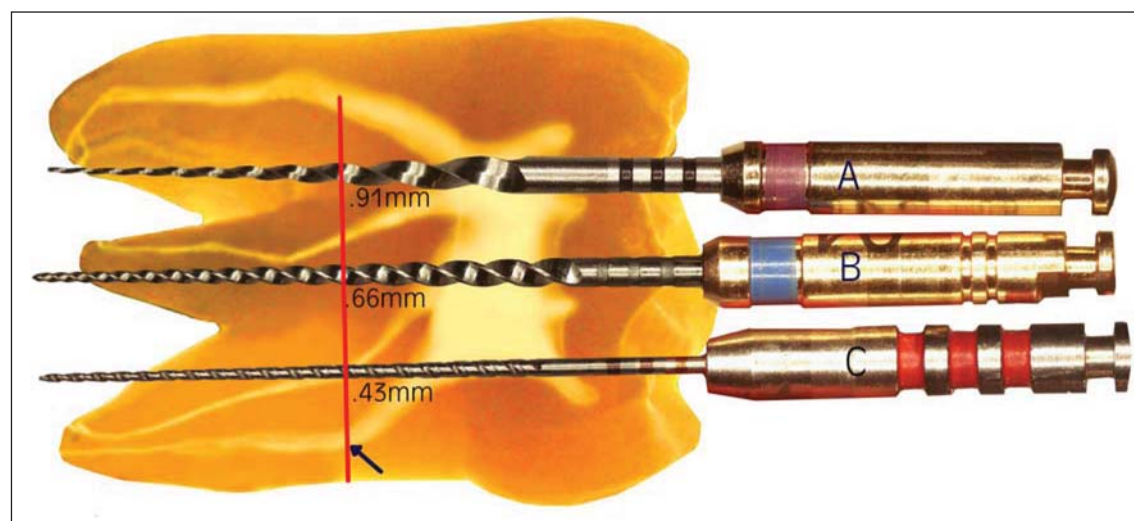


Fig. 67 In a coronal curvature 9 mm from the root apex, a ProTaper S1 (A) has a .91mm diameter, a Profile GT 30/.04 (B) has a .66mm diameter, and a Quantec 25/.02(C) has a .43 mm diameter. Since fatigue is closely related to the square of the radius, the Quantec 25/.02 file has approximately two times more resistance to fatigue than the Profile GT 30/.04 and four times more than the ProTaper S1. The larger diameters are more likely to transport the canal or break as a result of fatigue. Different brands of files were used only as illustrations; it is the diameters at the 9 mm level that makes the difference.



Fig. 68 (Left) The palatal and disto-buccal canals were easily prepared with 25/06 K-3 files. Since the canals were relatively straight, the curvature of the mesio-buccal canal necessitated not exceeding the taper of a 25/04 near the apex. Although the diameter of the file is larger than .50 mm at the fulcrum of the curvature, the efficiency of the K-3 design enabled the preparation to be accomplished in minimum time avoiding fatigue failure and canal transportation. (Right) The acute curvature with a small radius prohibits the use of larger tapered files near the apex without the risk of separation or canal transportation.

In order to avoid excessive flexion of the large diameters of files, many clinicians advocate removing tooth structure to minimize coronal or mid-root curvatures by repositioning the orifice of the canal and establishing

straight-line access. Although this technique is important, there was a propensity to carry the straight line beyond the point of initial curvature when root canal preparation was limited to stainless steel files. With the

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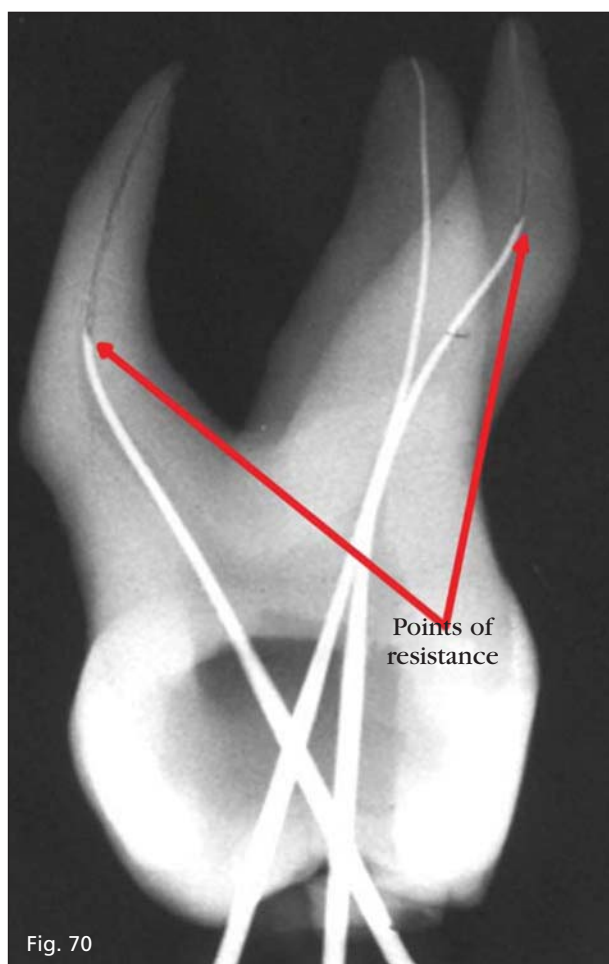
development of nickel titanium files, one has the advantage of being more conservative and not needlessly compromising valuable coronal tooth structures or restorations or risking coronal perforations or file breakage. Rather than abusing some of the recommended straight-line access steps of popular techniques that became ingrained in our rationale for stainless steel file techniques, incorporating smaller tapered rotary nickel

titanium files in the preparation technique can often accomplish the necessary, yet conservative, canal enlargement without routine intentional canal transportation. Even though the remaining tooth structure can seem to be adequately substantial after a less conservative approach rationalized as necessary for straight-line access, future demands or compromises on the tooth can be better served with the ability to save tooth structure.



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Once the working length of a canal is determined and prepared with a size 15 or 20 manual or rotary file, the position of the **most coronal curvature can be determined** by carefully inserting the same size stainless steel file **without rotation**. If resistance is met short of the working length it is an indication a curvature has been encountered. With experience, the position and approximate degree or radius of curvature can be determined by the amount of resistance the files meet, even while using nickel titanium rotary files.



Selecting a file that is smaller than the canal and inserting it without rotation until resistance is encountered can determine the location of curvatures. The amount of resistance can be an indication of the degree or radius of the curvature.

In addition to the tactile determination of curvatures, much information can be determined mathematically. For instance, if a canal has been negotiated to working length with a size 15/.02 file, a size 25/.02 file should easily go 5 mm short of the working length. This can be expected since removing 5 mm of the tip portion of a 15/.02 file would result in the same tip dimensions as the 25/.02 file. If the larger more rigid file encounters resistance before the 5 mm mark, this is an indication of a curvature.

File fatigue is also related to file design. The file design determines how much compression and tension stresses a file can accommodate as it rotates in a curvature, and also determines if the flexion occurs at particular locations along the working surface. The RaCe file, for instance, is essentially divided into alternating spiraled and non-spiraled segments, and virtually all of the flexion occurs at the junction of the segments. Rather than being more evenly distributed along the length of the working surface, the stress of flexion (the same could be said for torsion) occurs, especially on one half, the spiraled segments, of the instrument. Consequently, breakage usually occurs at the junction of the spiraled and non-spiraled segments where the stress concentration occurs. One needs to take this unique feature of the RaCe file into consideration when rotating in a curvature and be cautious of excessive time of rotation, particularly when rotating at the recommended speed of 500 rpm.

The stress of a file also varies with its orientation and the direction of forces in the canal, a property said to be *anisotropic*. The distance between the compressive stress and tension stress may change as a file rotates in a curvature and the total stress the file can

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accommodate becomes a more complex issue. For instance, a sword will flex easier with the fulcrum point on its broad surface rather than on its blade. The stress is directionally dependent.

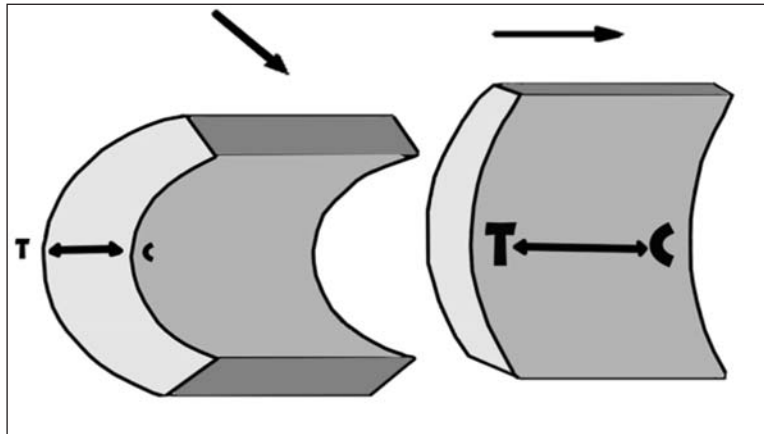


Fig. 71 Cross-section designs are the same in the above illustrations. In the left illustration, the force of flexion is directed at a point where there is little distance between the area of compression, C, and the area of tension, T, and bending can occur while minimizing stress. In the right illustration, the design is rotated 90 degrees from its original position. The distance between the area of compression and tension is increased and bending results in more stress.

33. What tactile sensations indicate efficient or effective rotary instrumentation?

How an instrument feels offers little information about the collective stresses on a file. Contrary to the practitioner's usual reliance on the tactile sensations of torsion for conventional hand files, stress on rotary files, as the result of the force of cutting, can most accurately be determined by testing. The results can be very different from the indications of tactile sensations. Since variations in torsion (those rotational forces that would urge the handpiece to move in a counter-clockwise direction if the file remained in a

stationary position) are difficult or impossible to feel, the tactile sensations of a rotary file are primarily due to *variations in pressure*, which can offer indications for a needed response. For instance, when applied pressure results in the negative pressure of screwing-

in, then an immediate response of removing the file from the canal is needed in order to prevent the stress of excessive engagement. Or when a greater pressure is required for continued advancement into the canal then the file should be removed in order to avoid ledging or subjecting the file tip to excessive stress. With no comparative basis for applied pressure, the uninformed user may likely select a file with inefficient scraping edges for having a smoother feel than one with more efficient less stressful cutting edges. *Cutting*

effectiveness, it should be pointed out, depends on more than just the sharpness of the cutting blades. It is also the result of the angle of incidence, helix angle, taper and flute design and the relationship each of these instrument features has with the file sequence and technique used.

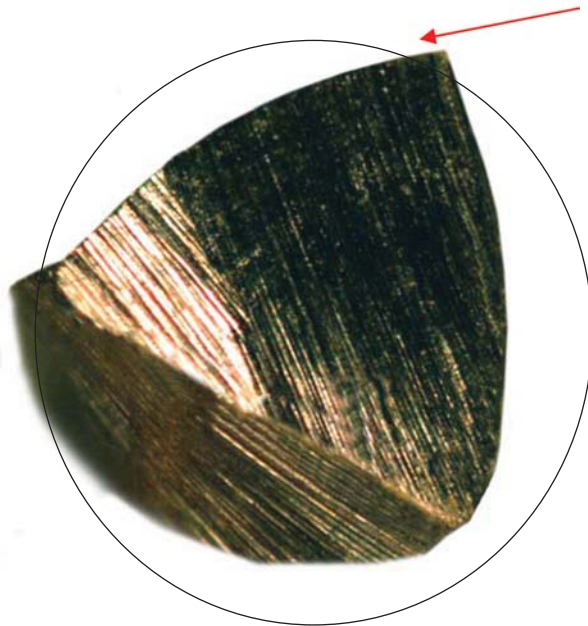
34. What determines the file's cutting ability?

The *cutting ability* of a file is primarily the result of its cross-section design when the taper and technique are the same. The angle of incidence of the blade and the width of the land, shown in cross-section perpendicular to the blade, are the best indications for

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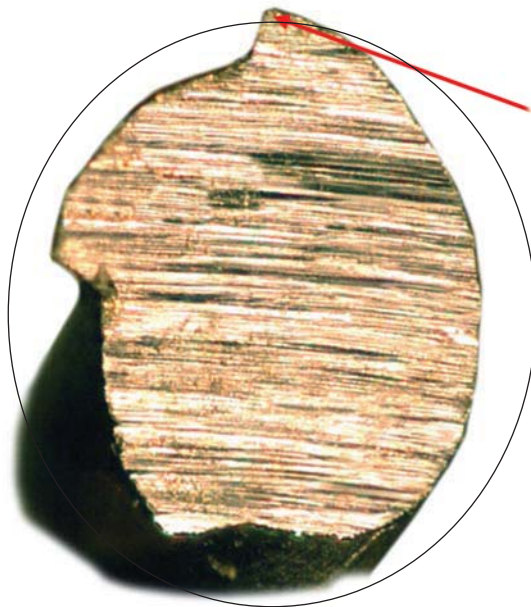
comparing different files for cutting ability. The helix angle certainly should be considered in conjunction with the cross-section design in order to maximize the efficiency of a particular file. It is important to note that

comparisons of cutting abilities of some files often change at different diameters along the working surface due to changes in the ratio of the depth of flute and file diameter, the width of lands, and the helix angle.



Note the negative angle of the cutting edge that, independent of other factors, would result in inefficient canal enlargement. However, the increasing conicity of the ProTaper that focuses the engagement (force per unit length) on a relatively small portion of the canal results in more effective enlargement but not to be confused with cutting efficiency.

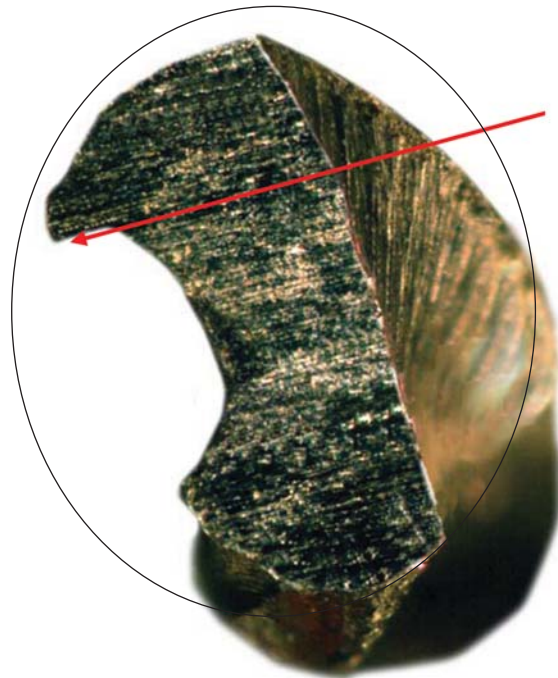
Fig. 72 ProTaper File Cross-section perpendicular to its cutting edge



Note that although the Hero file 'feels' sharp, the leading edge has been purposely dulled during manufacturing in order to reduce the screwing-in action. The cutting angle is actually negative.

Fig. 73 Hero file Cross-section perpendicular to its cutting edge

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Note the positive angle of the cutting edge. Little pressure is required for cutting to occur efficiently. Frequently, however, operator aggressiveness may result in excessive and unnecessary stress that may be counter-productive for canal enlargement.

Fig. 74 Quantec File cross-section perpendicular to its cutting edge

All files listed below were rotated at 300 rpm for 30 seconds at its .90 mm diameter with the same pressure on a plastic plate 2 mm thick. The depth of cut of each file indicates the cutting ability of file cross-section designs at its .9 mm diameter.

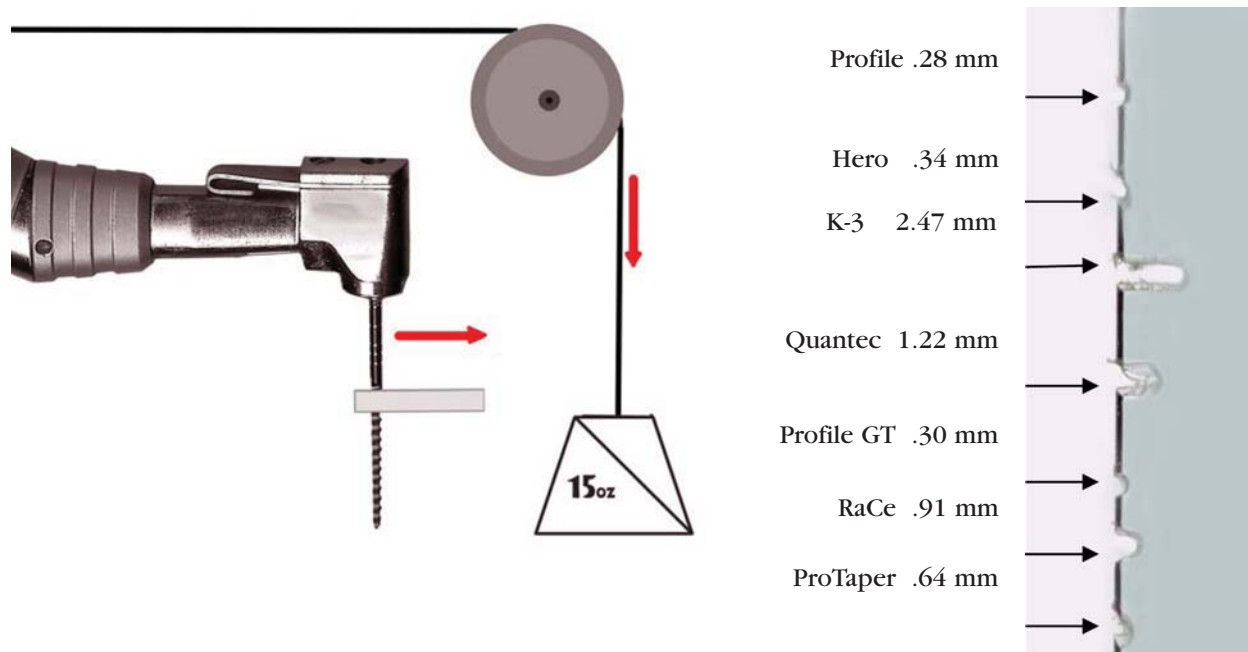


Fig. 75 Note that the depth of cut is greater with the RaCe and ProTaper than with the Profile or Profile GT files that have a more positive angle of incidence that should result in greater cutting ability. However, the Profile and Profile GT files have lands that limit the depth of cut. On the other hand, the K-3 and the Quantec files have the greatest depths of cut even though they have the widest lands. The positive cutting angles of the K-3 and Quantec have a greater influence on cutting ability than lands.

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The fact that ProTaper file design does not have as much cutting ability as the Quantec or K-3 designs (shown in the experiment above) is sometimes surprising for those who observe the ProTaper files advance into the canal more quickly during instrumentation. However, the differences in file engagement and total canal enlargement each file has with the depth of advancement

must be calculated. When comparing the dimensions of the S1 ProTaper file with the K-3 25/.06 file, for instance, the diameter of the K-3 is larger from its tip to 8 mm from the tip and more canal preparation occurs over the length of the file. Therefore, the K-3 may not progress as quickly into the canal space but the overall volume of enlargement is greater.

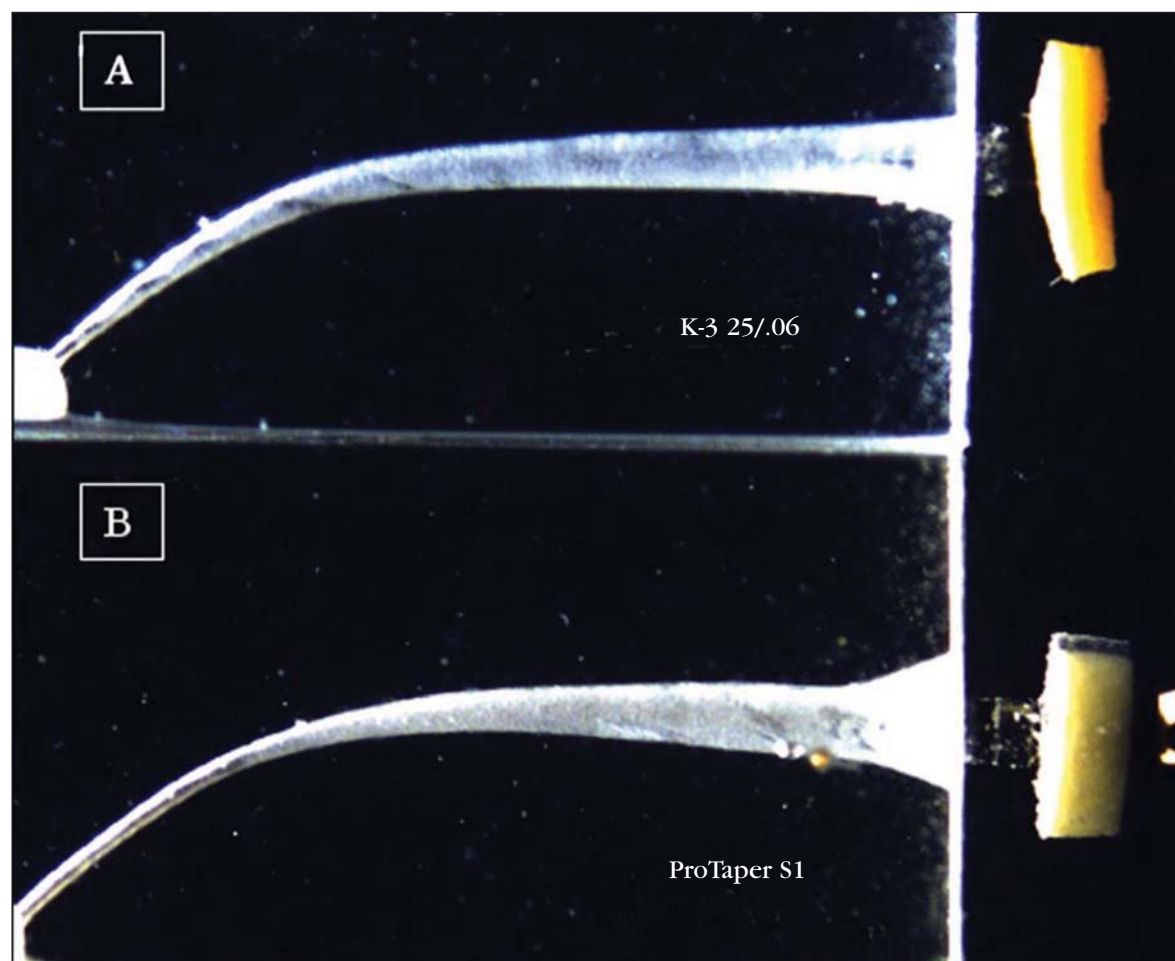
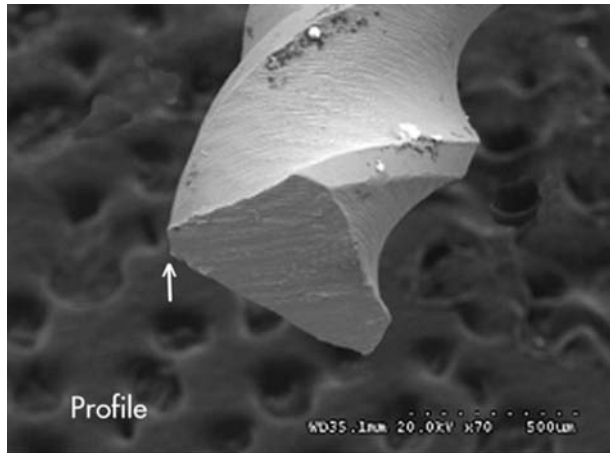
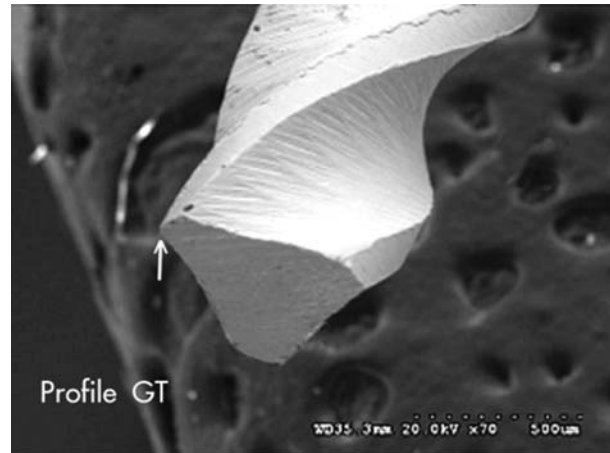


Fig. 76 Plastic block (A) was prepared with a 25/06 K-3 file. Plastic block (B) was prepared with a S1 Protaper file. Both files were advanced the same depth to the terminus of the canal with the same force of insertion. The K-3 removed substantially more material per unit time than the Protaper file when carried to the same depth. However, the Protaper file advanced more rapidly than the K-3 giving the appearance of being more efficient.

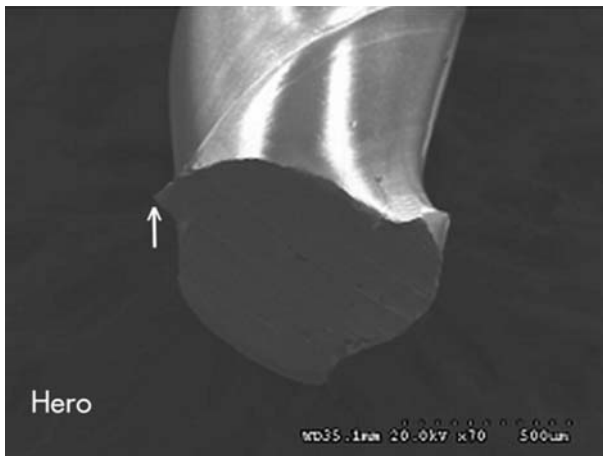
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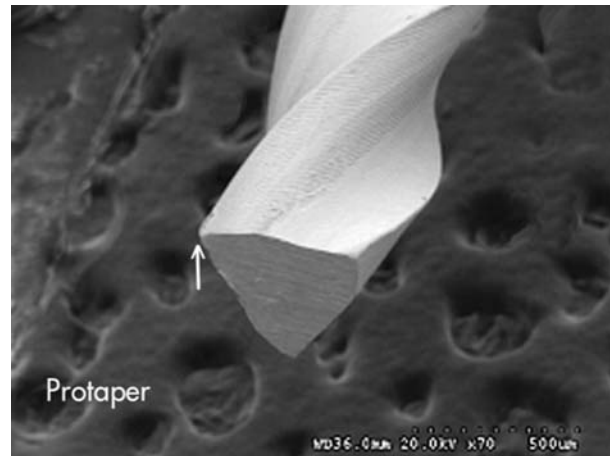
Profile 11%



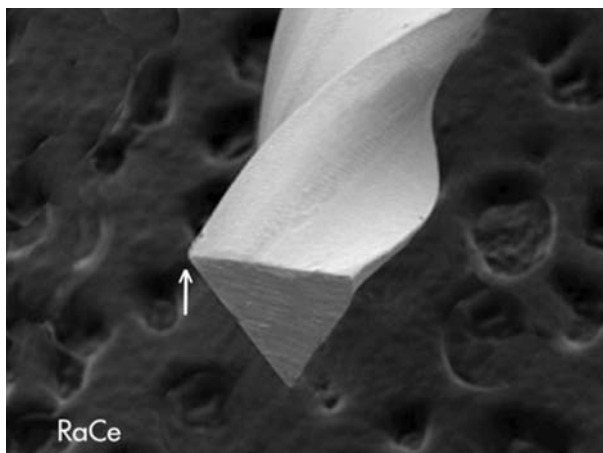
Profile GT 12%



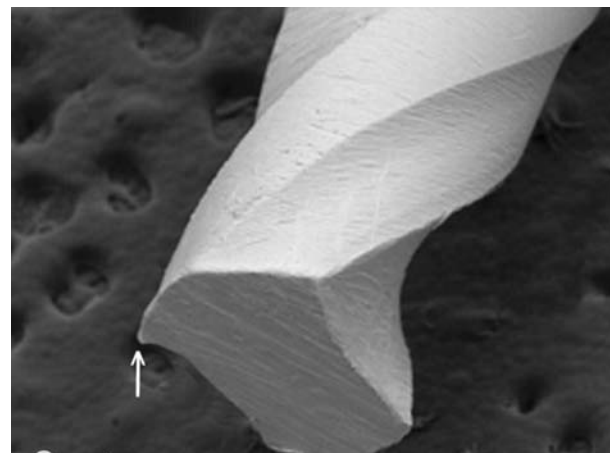
Hero 14%



ProTaper 26%

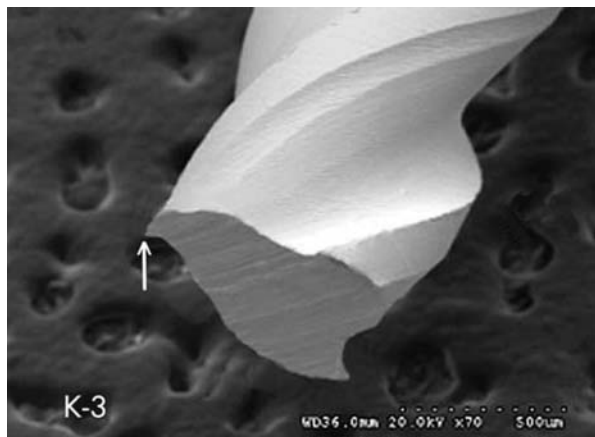


RaCe 37%



Quantec 49%

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K-3 100%

Fig. 77 The cutting ability of each cross-section design was measured at the .90 mm diameter of each file. Comparisons of cutting abilities were made as a percentage of the K-3 file which had the greatest cutting ability. The white arrows indicate the cutting edge of each file.

Cutting ability is synonymous with cutting efficiency. However, the term cutting efficiency of a file would more appropriately be reserved for describing the entire working surface that becomes engaged rather than a measurement at one diameter. As can be seen from the photographs below, some cross-sections differ from the manufacturer's representations and the cross-sections of some of the instruments change with a change in instrument size and diameter. The manufacturer's representations may differ in order to emphasize certain features of the file or to accentuate the file's most complicated design, usually most

The following images compare the manufacturers' illustrated cross-section design shown at the left vs. the actual cross-section shape at different levels on the working surface, at 1mm, 6mm, and 14mm from the file tip.
Photographs and SEMs courtesy of FKG Dentaire

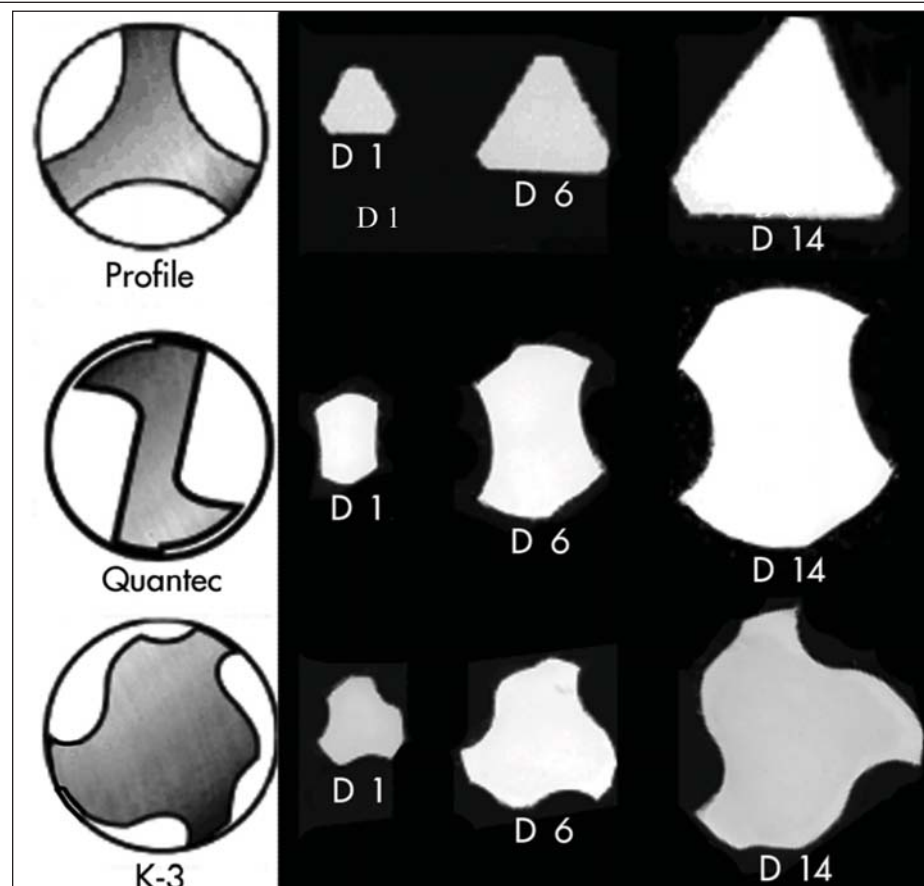
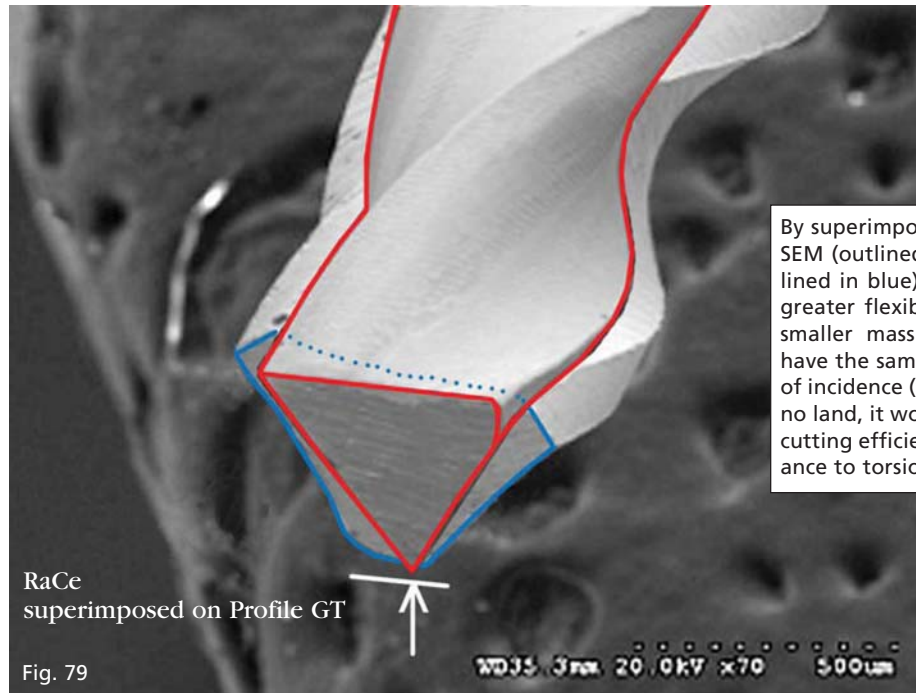


Fig. 78

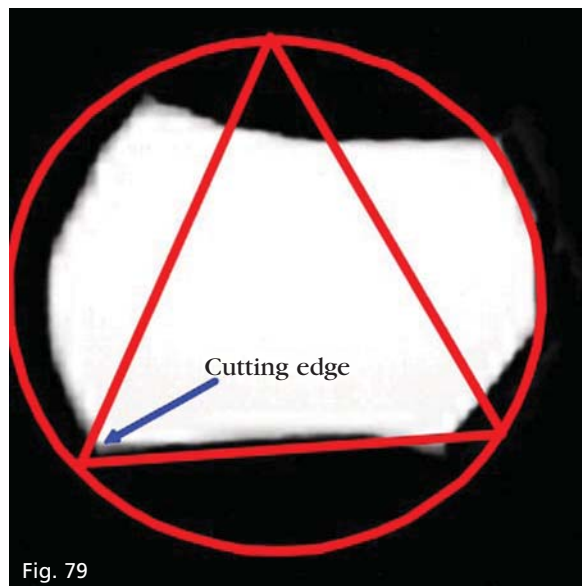
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evident at its largest diameter. The file designs at smaller diameters may differ from the larger diameters for two reasons. One is manufacturing limitations for maintaining the design at smaller diameters and the other reason is to add strength to the

file at its tip by reducing the depth of flute. In any case, it behooves the operator to understand that cutting characteristics may change along the working surfaces of a particular file and how the changes affect the actions of the file.



By superimposing the outline of the RaCe file SEM (outlined in red) on the Profile GT (outlined in blue) having the same diameter, the greater flexibility of the RaCe file due to its smaller mass becomes apparent. Both files have the same 60-degree rake angle or angle of incidence (white arrow). Since the RaCe has no land, it would be expected to have greater cutting efficiency and flexibility but less resistance to torsion failure.



With the outline of the RaCe file superimposed on the photograph of the Quantec at its .25mm diameter, one can see that the rake angles of both files are the same. However, the cutting angle of the Quantec would be slightly more positive when viewed in a section perpendicular to its cutting edge whereas it would remain the same on the RaCe. With lands, but having a sharper cutting angle, only testing can determine if the Quantec has greater cutting efficiency at this diameter. The RaCe file has less cross-sectional mass and will be more flexible.

When the file is studied as a whole, including the changes in shapes and helix angles along its working surface, we begin to understand that testing one aspect of a single file size at a particular diameter as one of a file series may not be definitive in determining its effectiveness for rotary instrumentation. For instance, testing indicates that the Quantec file has 49% of the cutting ability of the K-3 at its .9 mm diameter when only 180 degrees of the file is engaged. However, the Quantec file requires approximately one half the torque to enlarge a 7 mm section of a canal that is .40 mm in diameter to a size 1.10 mm diameter when engaged 360 degrees. This observation points out the fact that the lateral cutting ability can differ from that of penetration efficiency. The results are not contradictory; only more factors need to be put in the equation and, in the case of the K-3 and the Quantec, two other factors are as important as cutting ability: the greater total land width of the K-3 diameter results in greater resistance during rotation and the greater depth of flute of the Quantec reduces the amount of compression of the debris and the resistance of its rotation. The net result is the K-3 is two times as efficient as the Quantec when their circumferences are not fully engaged, but the Quantec has two times the efficiency when the circumferences are fully engaged. Keep in mind these relationships may change when using different diameters.

35. How does cutting ability relate to canal transportation?

How quickly canal transportation occurs depends on a file's cutting ability per unit time. However, that is not to say that if one file has a greater cutting ability than another, it will necessarily have a greater tendency to transport a canal. Two design features, lands and asymmetrical cross-sections, can be incorporated to minimize transportation without reducing circumferential cutting ability. Since a land extends the same distance from the file's central axis as the cutting edge, it helps distribute the pressure of the blades more evenly around the circumference of a curved canal as opposed to canal transportation of files that lack lands that results in concentrating all of the pressure of the cutting edges on the canal wall that would straighten the curvature, on the inside of the curvature coronal to the fulcrum point, and on the outside wall apical to it. As the radius of the land remains in contact with the canal wall on one side of the curvature, it forces the cutting edge to function on the opposing wall. Similar to the way a safety razor limits blade engagement, wide lands limit blade engagement in the wall of a canal. As rotation occurs, more uniform cutting occurs on each wall of the canal as compared to cutting edges that have no lands.

Wide lands are not the only means of accomplishing more uniform cutting on each side of the canal; asymmetrical efficiency of each of the cutting blades can have a similar result. It might be said that it takes an asymmetrical file to result in greater symmetrical canal enlargement.

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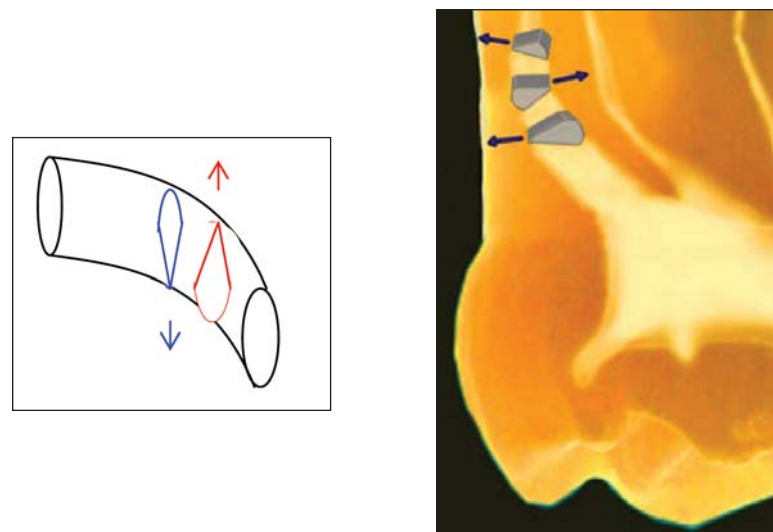


Fig. 81 The force of cutting for the cross-section segment of the file outlined in blue and the force of cutting for the cross-section segment outlined in red are directed in opposite directions. The result of the asymmetrical cross-sections or of the lands is more uniform cutting on each surface of the canal, even though the file has a tendency to assume a straight position.

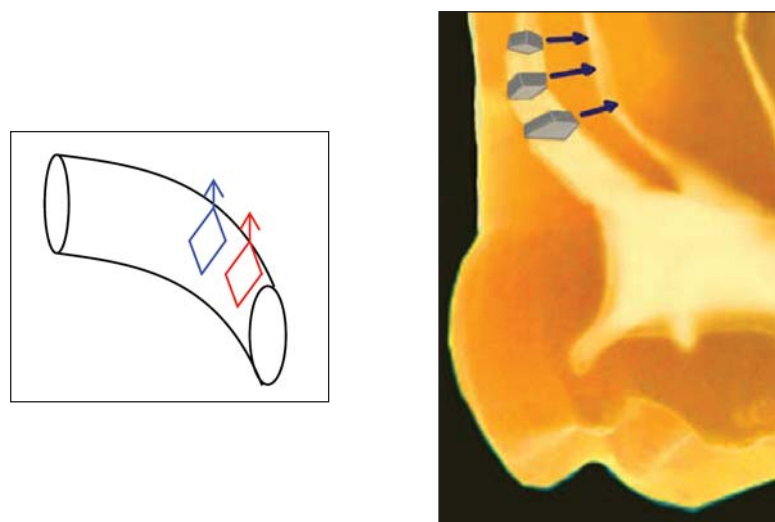


Fig. 82 The force of cutting for both cross-section segments of a symmetrical file without lands are directed in the same direction and the result is a tendency for canal transportation. The forces are directed on the outside canal wall beyond a curvature (as illustrated in the drawing on the left) and are directed on the inside canal wall in a curvature (as illustrated on the right).

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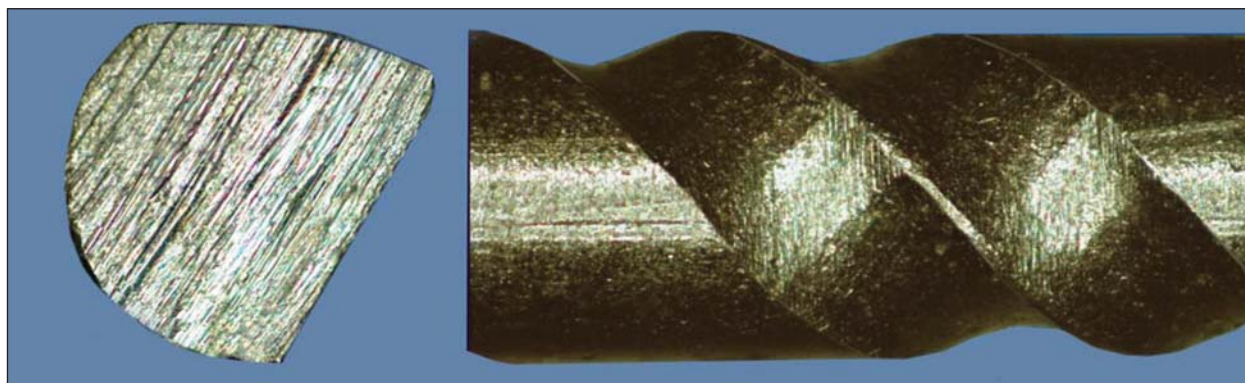


Fig.83 Illustrated above, the A-file introduced by NT Co. represents the first asymmetrical file designed to maintain the central axis of a canal around a curvature.

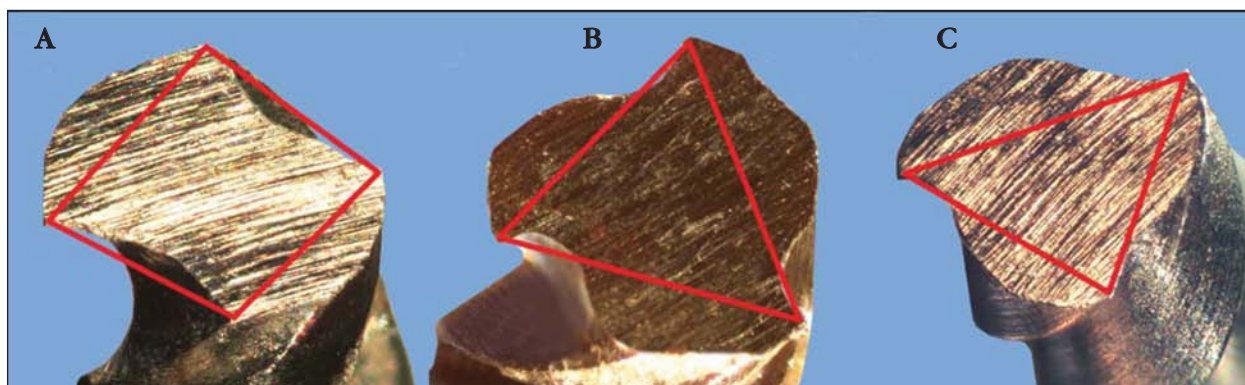


Fig.84 Other asymmetrical files include the (A) Quantec, (B) K-3, and the (C) Micro-Mega prototype files. Although the geometric asymmetry is not so pronounced, the blades of each file have different efficiencies that contribute to more uniform cutting.

36. Do some files seem to screw into the canal?

Often underestimated in importance is the fact that **most of the total torque required** to rotate a file can be due to the force of **screw-ing-in** caused by the blades becoming engaged by cutting into the canal wall to form chips without dislodging them. When the blades are parallel or the helix angles are the same along the working surface, the file becomes an effective screw. Torsion results when any screwing-in force is resisted and can cause the file to become locked in the canal. Parallel blades and more spirals are a carry-over from the hand file design when

instruments were twisted during manufacturing and the 'watch-winding' motion was used as a reaming technique. Screwing-in forces can actually be augmented with sharper cutting angles further complicating the formula for efficiency.

Several file manufacturers utilize accelerating helix angles to reduce the screwing-in forces. For instance, a 22-degree helix angle at the tip of the file may be graduated to a 45-degree angle at the handle end. As both ends of the working surface are engaged, the different angles have different screwing-in rates, feed rates, and much of the torsion of screwing-in is reduced. However, most of the working surface of the file with graduating

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helix angles needs to be engaged before the different blade angulations have much benefit in canceling out some of the screwing-in forces and when most of the file is engaged that in itself increases torsion. If only a small

portion of the file becomes engaged, the screwing-in forces may require most of the force for rotation. The operator may notice this pulling-in force if only a short portion of the file becomes engaged in a constriction.



Fig. 85 The helix angle at the tip end and handle end of the Profile GT 40/04 are approximately the same. The helix angle at the tip end and handle end of the Profile 40/04 are substantially different. The Profile screws-in substantially less than the Profile GT when fully engaged. However, when only a small segment of the working surface is engaged there is no significance difference. (see Chart 86 below)

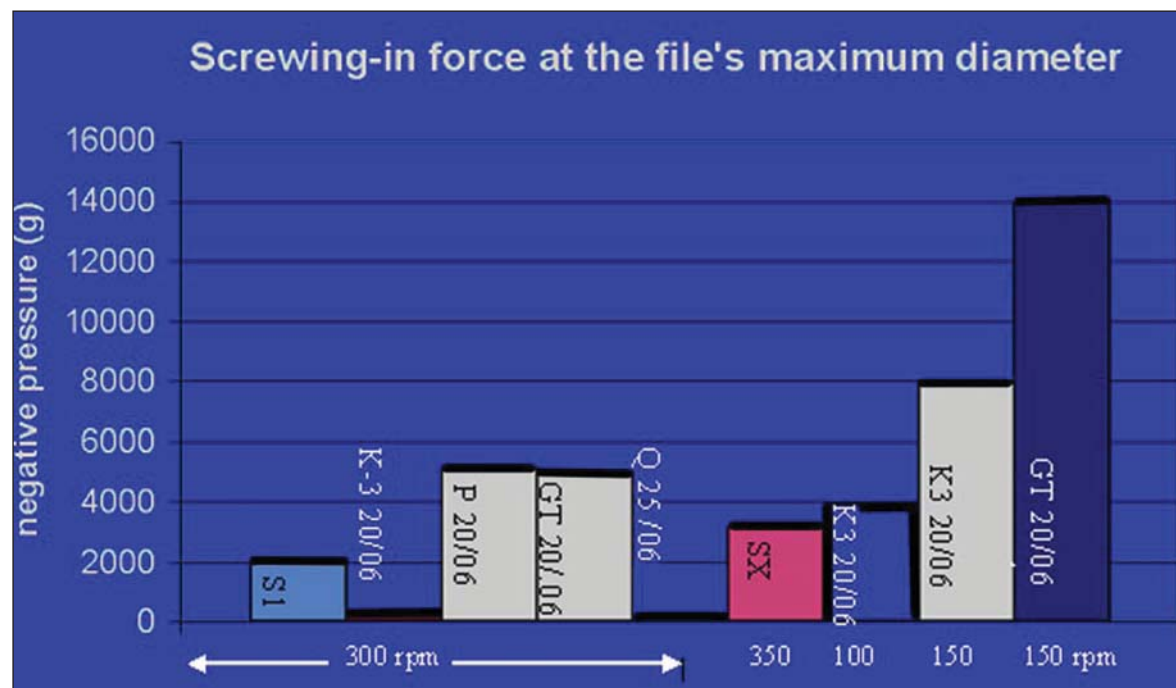


Chart 86 The files were advanced 1 mm/s into a size 45 canal 2 mm deep. Note that the Quantec file (Q) had no screwing-in forces and the K-3 file had minimum screwing-in forces at 300 rpm. The K-3 file had substantially greater screwing-in forces at 100 and 150 rpm. The Profile GT (GT) file had greater screwing-in forces at the slower speed of 150 rpm.

The speed of rotation can have a significant influence on the screwing-in forces and the resulting torsion. The optimum rotation speed for efficiency remains approximately the same independent of the canal anatomy. Slowing the speed of rotation as a precautionary measure can result in additional torsion because the screwing-in forces may increase by allowing the blade to become too deeply engaged to dislodge the chips that are formed.

The most efficient design incorporates only the minimum number of spirals that are necessary to effectively remove debris. In doing so, more positive cutting angles can be utilized and the decrease in the number of spirals of the blade reduces the amount of its engagement. The result is a reduced required torque for rotation and increased efficiency.

37. How spiraled should a file be?

Having shorter file working surfaces, using less engagement and shorter strokes for apical insertions, and irrigating constantly during canal preparation can reduce the number of spirals necessary for removing debris from the canal. Any reduction in the number of spirals can result in a substantial reduction of the required torque for rotation. Flexibility needs to be considered for the reduction limit of spirals because fewer spirals also result in less flexibility for ground files. The file's efficiency for removing debris is also a consideration.

The RaCe file by Brasseler USA and FKG Dentaire (Switzerland) significantly reduces

the torque of rotation and screwing-in forces by incorporating alternating non-spiraled and spiraled segments along its working length. The non-spiraled portion cancels much of the screwing-in forces of the spiraled portion. By eliminating some of the spirals that consequently reduce the amount of file engagements, RaCe files have the added benefit of reduced torque requirements.

Although the Quantec file demonstrated greater cutting ability of cross-section design than the RaCe file, ProFile, and ProFile GT, less torque was required during canal preparation with the RaCe file. The reduced torque requirement is due to the reduction of engagement from having fewer spirals and the reduction of the screwing-in tendency from alternating the helix angles. The net advantage, if any, is difficult to determine, because RaCe file requires less torque to fail. As shown previously, the RaCe file is also more flexible than the other files tested. Essentially, all of the bending takes place at the junction of the spiraled and non-spiraled segments where the torsion stress also becomes concentrated. Both of these factors account for the file's increased strain during torsion and flexion, particularly when considering the recommended rotation speed of 500 rpm. However, the low torque requirement and greater flexibility make the RaCe file an excellent instrument for avoiding transportation and negotiating delicate curvatures, ledges, and blocked canals if caution is used to compensate for its increased tendency for failure.

RaCe file by Brasseler USA and FKG Dentaire

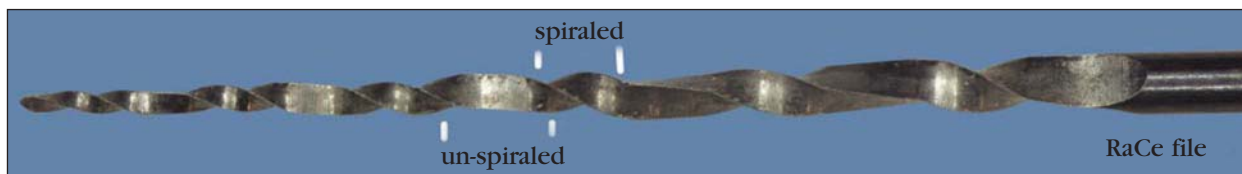
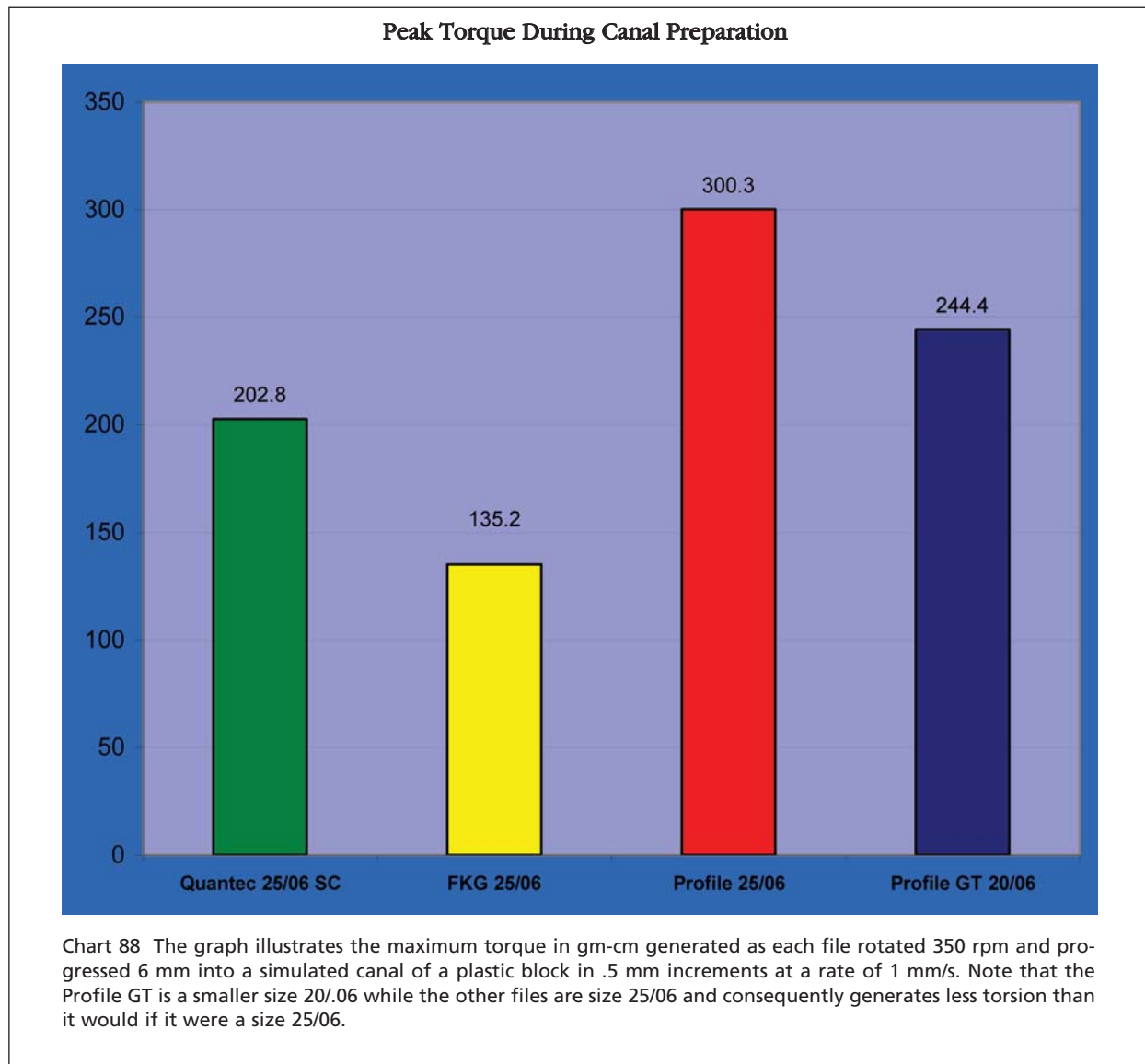


Fig. 87 By incorporating non-spiraled segments with spiraled segments along its working surface the RaCe file reduces the screwing-in forces and the amount of engagement.

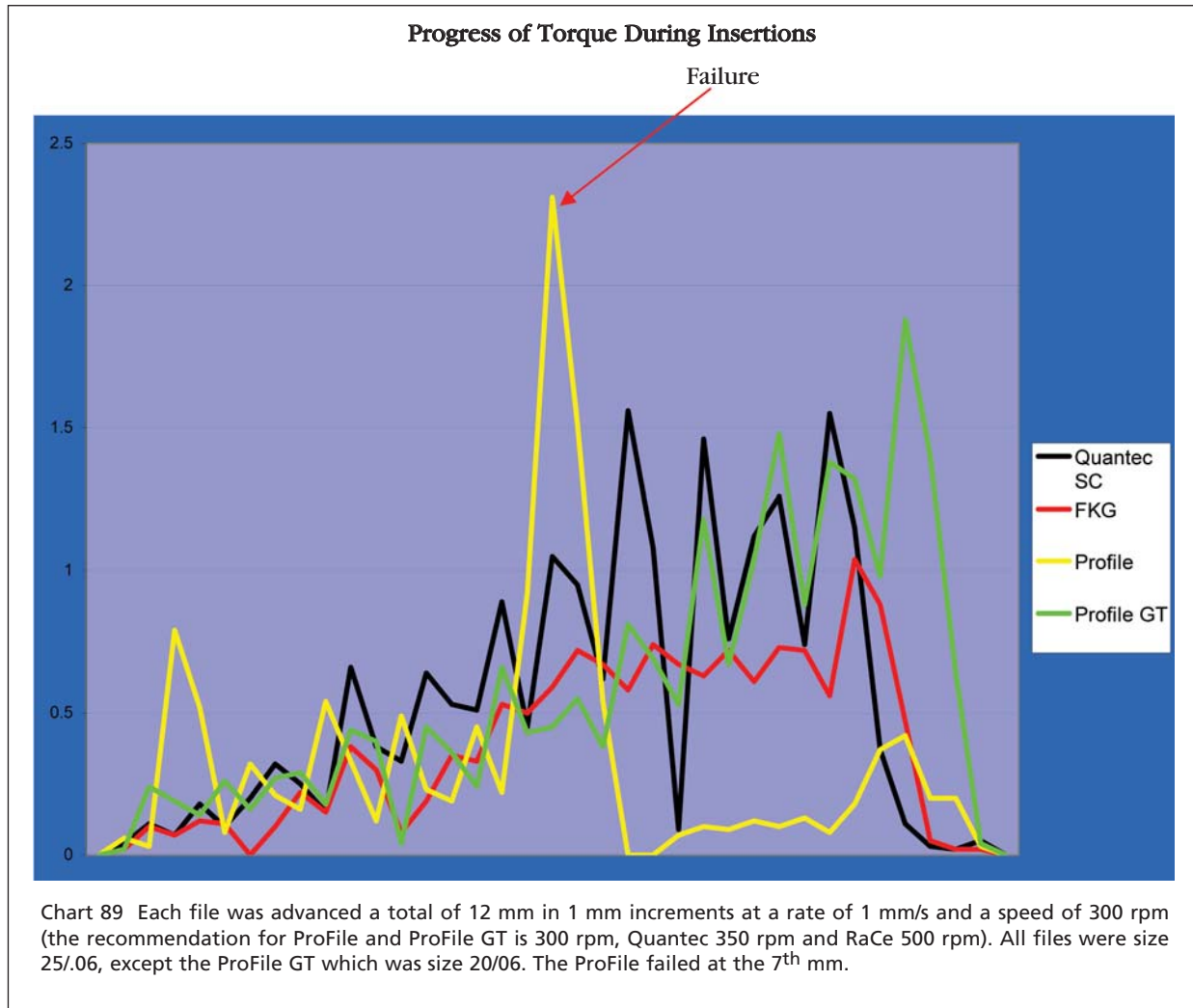
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An observation that is noteworthy while testing the torque generated by different instruments, is the change of torque during insertions and withdrawals while negotiating the canal. The RaCe file demonstrated very little torque difference during insertion and withdrawal since screwing-in forces are minimized by its design.

Also noteworthy was the consistency of results when comparing multiple batches of each file. The ProFile and ProFile GT had the greatest deviations from median for the recorded torques for each insertion and withdrawal resulting in less predictability for torsion failure.

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38. Are there other file designs to reduce the torque of screwing-in?

With the realization that eliminating some screwing-in forces can significantly reduce torsion stress, the designs of future files will probably place greater emphasis on this concept. Actually, one of the first NiTi rotary files, the Sensor file (NT Co.), approached the screwing-in problem with an effective

concept, dissimilar helix angles. At least one blade of the file had a helix angle that was different from the other blades along its working surface. Having more than one helix angle, the blades and flutes intersect along the working surface and the screwing-in forces created by one helix angle can cancel, at least partially, the screwing-in forces of the dissimilar angle. Modifications of this concept can be useful in future designs.

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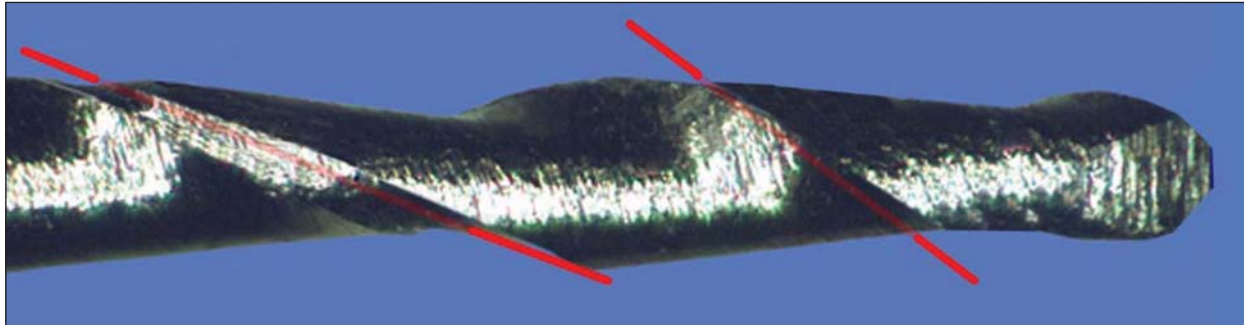


Fig. 90 The Sensor File introduced by NT Co. incorporated dissimilar helix angles to minimize screwing-in forces. A secondary flute, $\frac{1}{2}$ as deep, intersects the primary flute by having a different helix angle.

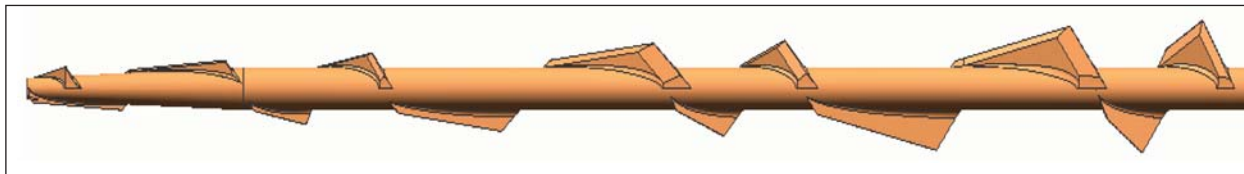


Fig. 91 A computer generated designed file illustrates three features that might be incorporated in future files made possible by casting or EDM production processes. (1) Blade segments are not continuously spiraled around the shaft on the file. Each segment circumscribes only 25% of the file circumference reducing the torsion of blade engagement. (2) Each blade has a different helix angle that reduces torsion from screwing-in forces. (3) The blades project axially from the shaft rather than being ground into it to increase flexibility and reduce the areas of stress concentration to reduce the propensity for breakage.

The Non-spiraled file with sharp rake angles, designed by the author and prototyped by Cloudland Institute LLC, explores a novel concept that eliminates all screwing-in forces and minimizes file engagement by using non-spiraled flutes. Absent screwing-in forces that facilitate apical advancement into the canal, the *Non-spiraled file is atypical in requiring more apical pressure to be applied in order to accomplish canal enlargement, but having proportionately more strength*

for doing it since less torque is required. The Non-spiraled file has one extremely interesting action when it becomes bound. Since it has non-spiraled flutes, any twisting deformation that occurs from being bound results in the formation of a reverse screw configuration that causes the file to unscrew from the canal or resist any additional progress into the canal. This unique feature can be used as an indication that excessive force is being applied to the file.

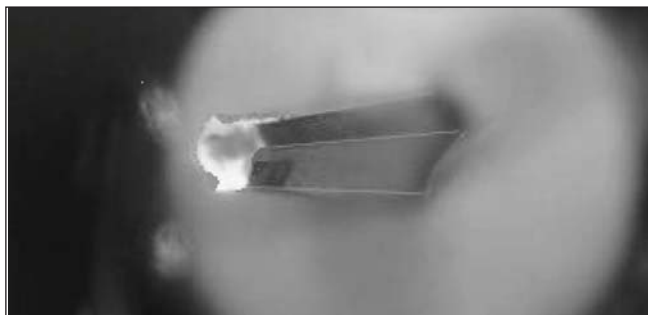


Fig. 91 **Non-spiraled file (prototype) by Cloudland Institute**

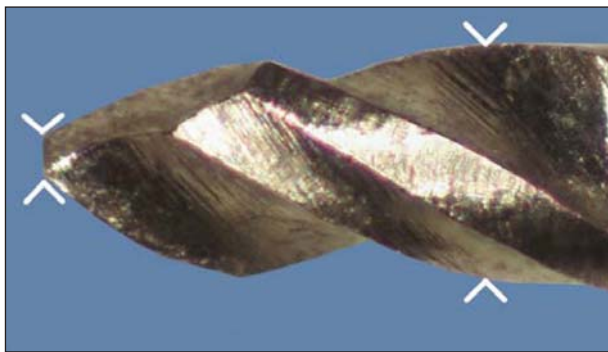
The non-spiraled file has the unique design of having no spirals. All screwing-in forces are eliminated and the blade engagement is reduced. The result is a substantial reduction of torsion stress with high cutting efficiency. If the tip should become bound the file begins to twist to form a reverse screw that results in a backing-out action of the file as opposed to the screwing-in action of other files.

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39. What are the different types of file tips and what differences do they make?

File breakage can occur by applying excessive torque while attempting to enlarge a canal that has a smaller diameter than the non-cutting portion of the file tip. Instrument tips have been described as cutting, non-cutting and partially cutting although there is no clear distinction between the types. The tip has two functions. One function is to enlarge the canal. The other function is to guide the file through the canal. Without understanding

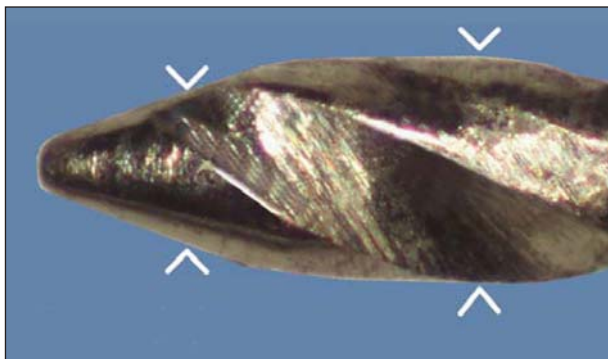
the tip design of a particular instrument, one is apt to either transport the canal if the tip is capable of enlarging the canal and it remains too long in one position, or encounter excessive torsion and break the file if a non-cutting tip is forced into a canal having a smaller diameter than its tip. Transportation of the original axis of the canal can occur by remaining too long in a curved canal with a tip that has efficient cutting ability. On the other hand, there is no need to remain too long in one position and the efficient cutting can facilitate enlarging or negotiating constricted or blocked canals.



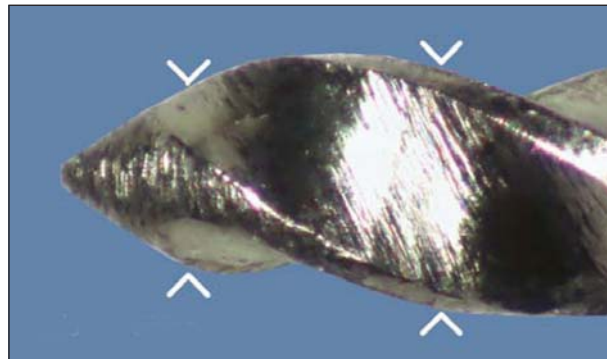
Quantec SC 20%



Quantec LX 69%

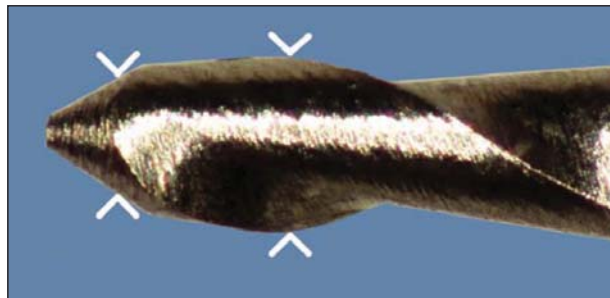


Profile 69%

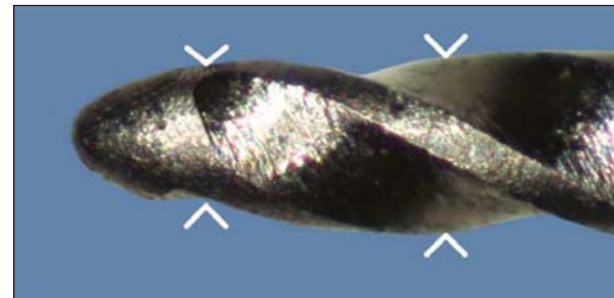


K-3 70%

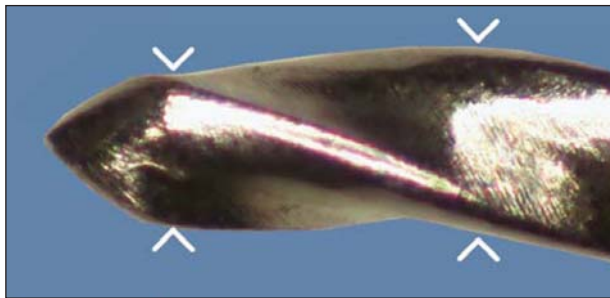
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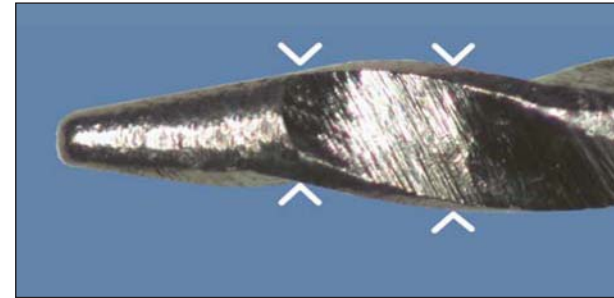
M2 72%



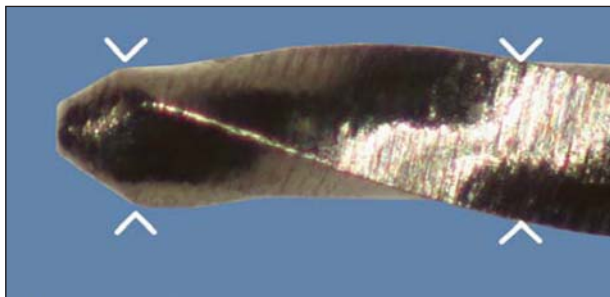
Profile GT 77%



Hero 80%



Lightspeed 81%



Protaper 82%

Fig. 92 The above files are arranged in order of cutting diameter at the tip relative to the file's tip size. The tip of each file is designed to have an effective cutting edge at a diameter that is a percentage of its tip size (one millimeter from the actual tip). If the diameter for effective cutting is greater than the canal diameter, the canal will be enlarged by burnishing rather than by cutting and increased torsion will result. For example: A size 25 Lightspeed has a tip that will effectively enlarge a canal without burnishing that is 80% that diameter or a size 20 canal. However, a size 30 Lightspeed will begin burnishing a canal that has a diameter larger than .24mm (80% of 30) and a half size is needed to prevent undue torsion. The greater the tip size becomes, the more critical the percentage is.

The angle and radius of its leading edge and proximity of the flute to its actual tip end determine the cutting ability of a file tip. The cutting ability and file rigidity determine the propensity to transport the canal. ***What must be remembered is that as long as the file is engaged 360 degrees, canal transportation cannot take place.*** Only with overuse does the file begin to cut on one side causing transportation to occur. The tendency for the file to cut on one side is the result of rigidity. For example, the

RaCe file has a sharp edge and flute that extends to the actual tip, yet it is very flexible making it an excellent file to enlarge canals beyond curvatures and negotiating ledged or blocked canals without transportation. On the other hand, the Light Speed file is excellent for following curvatures when enlargement near the tip is not required. The Quantec SC file is very effective in enlarging calcified canals or canals that might result in excessive torque with other files.

A good beginner's rule to follow is: if the canal is smaller than the file, a cutting tip should be used. If the canal is larger than the tip, a file with a less effective cutting tip will help prevent transportation. As the operator gains skill, tips with greater cutting ability can be used to reduce stresses on the file and expedite canal enlargement without transportation.

Even though the Quantec SC, which has a “cutting tip,” demonstrates significantly less required torque for canal preparation, there is reluctance for many clinicians to take advantage of its efficiency, and “aggressiveness,” even in situations where the canal size is much smaller than the file needed for preparation. The reason cited is the tip’s ability to transport the canal. It should be pointed out, however, that transportation due to a cutting tip occurs only from over-instrumentation of a canal that has first been adequately prepared with that instrument; it cannot transport unless it was already in the correct enlarged position. A file that has a diameter large enough to be 360 degrees engaged in a curvature will not transport the canal as easily as a file that fits loosely in the canal so that only one side of the file is cutting one surface of the canal. Transferring the aggressive nature of the operator as a characteristic of the file can be a source of clinical error. A cutting tip proves most advantageous when attempting to negotiate a canal that

has a diameter smaller or approximating the file tip diameter. Once the canal has been negotiated to working length with one tip size, using non-cutting tips on subsequent files of the same tip size is advisable if transportation is a concern.

40. How do I determine the optimum rotation speed?

The optimum speed of rotation is determined by two factors: the helix angle and the amount of engagement. The feed rate of the file, or how fast the file would screw-in if no resistance were met or no force were applied, is determined by the helix angle. If the file progresses into the canal at the same rate as its **feed rate**, maximum engagement occurs with minimum chip dislodgement that results in maximum torque. For this reason, slowing the rotation for the sake of reducing the threat of failure in complex anatomies can actually increase the amount of engagement and the likelihood of failure if the rotation speed approaches the feed rate determined by its helix angle. If the file progresses into the canal faster or slower than the feed rate, the depth that the blades become engaged is reduced and greater chip removal occurs. The optimum speed is the speed that causes the least amount of stress, and changing to a slower or increased speed can increase the stress on the file even in compound curvatures.

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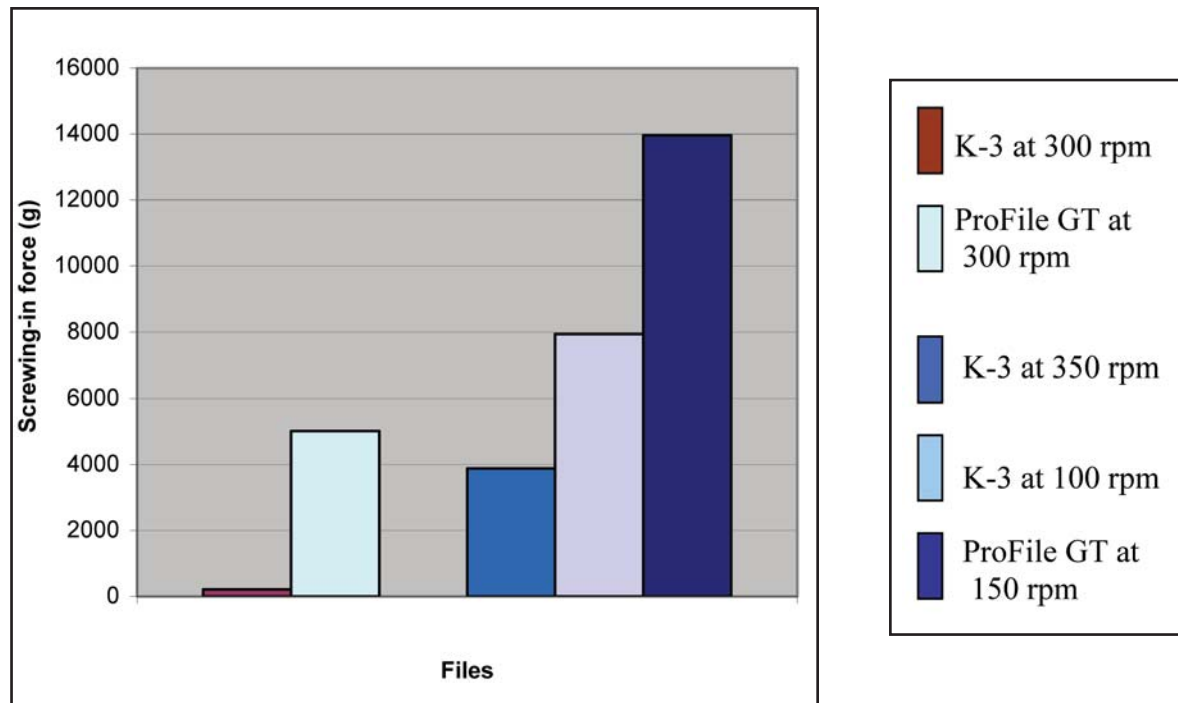
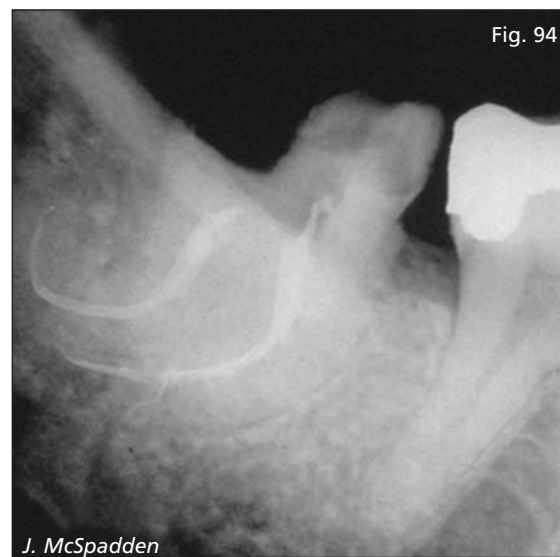
Screwing-in force at maximum diameter of the file at different speeds

Chart 93 The files were advanced into a simulated canal of a plastic practice block having a .40 mm diameter and a 7 mm length at the rate of 1 mm/s. Note that the torque increased as the speed deviated from 300 rpm. Although the suggestion is often made to slow the ProFile GT to 150 rpm from the recommended speed of 300 rpm in complex anatomies as a precautionary measure, the torque and screwing-in action increase substantially at that reduced speed for the size .20/.06 taper ProFile GT.



Although the clinician might consider slowing the speed of file rotation during the preparation of a complex curvature as a precautionary measure, the consequence can be increased torque and possibility of file failure. Optimum speed does not change in difficult anatomies if the file is to be engaged 360 degrees in the canal. Note also that straight-line access in this particular tooth would be of little benefit with this type curvature without compromising valuable tooth structure.

Optimum rotation speed is also determined by the amount of the circumference of the file that is engaged. If only the side of the instrument is in contact with the canal, the force of torsion is virtually eliminated and the speed of rotation can be substantially increased to augment its effectiveness *if* the file is prevented from becoming circumferentially engaged and the tip remains passive. Using this technique can be very expeditious in preparing an *anastomosis, fin, or intentionally relocating the orifice of the canal*. If only a short length of the file can become engaged, as with a Light Speed instrument, cutting can be more efficient at higher speeds of rotation.

41. How does file engagement affect breakage?

Torsion is directly related to the amount of file engagement. The torque required to rotate a large area of the working length of a file may cause excessive stress on the smaller diameter portion of the file, resulting in failure. Since the area of the working surface is comprised of the length and the diameter, the torque required to rotate a tapered

instrument with 16 mm of engagement may be significantly more than two times as great as is required for one with 8 mm of apical engagement. Reducing the length of the working surface can certainly reduce the potential of engagement and, therefore, its propensity for failure.

The minimum torque required for the maximum diameter portion of the file to function in the canal can be more than sufficient to break the smaller tip diameter portion of the file if it becomes bound in the canal. For instance, the maximum fluted diameter (1.00 mm) of the Profile GT size 20/.04 tapered file, which has a 20 mm working surface, is five times the diameter of the tip (.20 mm) and requires approximately five times the torque for rotation during instrumentation. Yet, the torsion strength of the tip can be less than 1/25 the torsion strength of the largest diameter, since the strength is closely related to the square of the diameter. The Profile GT 20/04 taper file is particularly vulnerable to excessive torsion if its total working portion becomes engaged; it has the longest working surface (20 mm), 4 mm longer than the 16 mm conventional length,

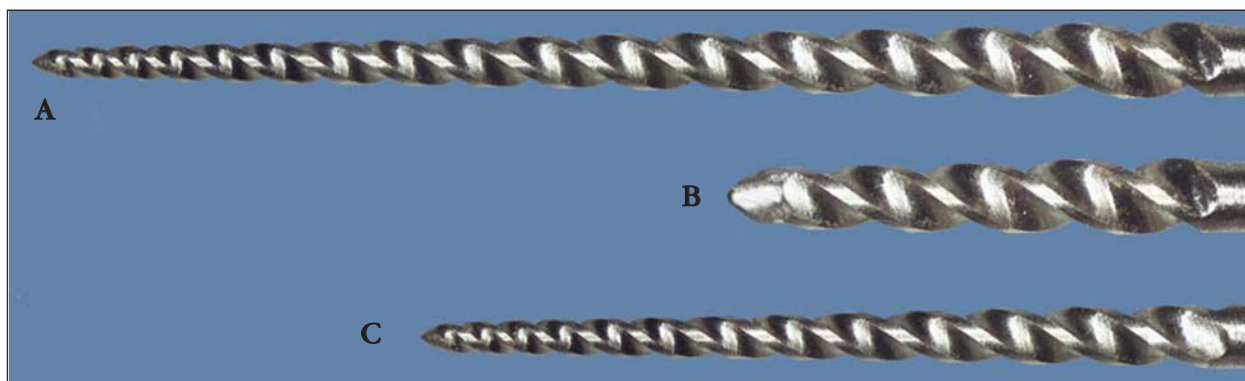


Fig. 95 The torque required to rotate a fully engaged file (A) may be more than twice the total torque required to rotate fully engaged files having the same total working surface (B and C). The torque required to rotate the fully engaged file (A) may be sufficient to break the smallest tip portion of the file if it should become bound. However, the torque required to rotate the fully engaged file (B or C) may not be sufficient to break the tips of these files.

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and the smallest tip diameter. Reducing the difference and distance between the tip (D min) and maximum diameter (D max) can enhance one's ability to avoid applying exces-

sive stress. By increasing the tip size from a size 20 to a size 25, for instance, the torsion strength can be increased 50%, even though the increase in diameter is only .05 mm.

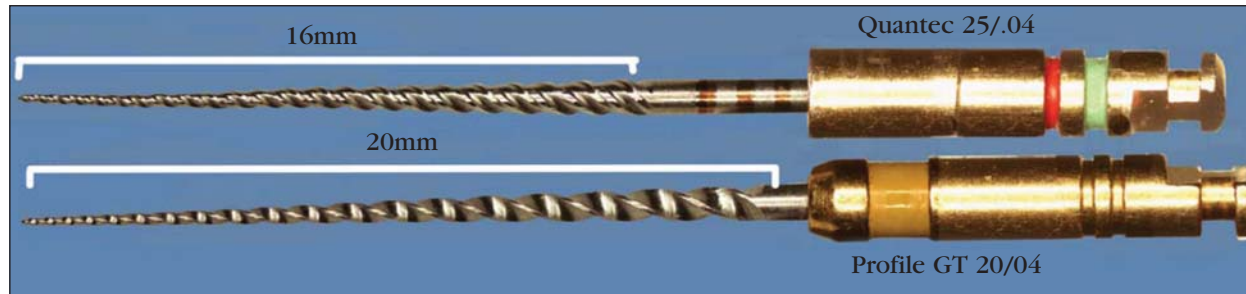


Fig. 96 The Profile GT size 20/.04 taper has 20mm of working surface significantly increasing the torque required to rotate a fully engaged file compared to 16mm working surfaces. The torque required to rotate a fully engaged file can be more than sufficient to cause breakage near the minimum diameter if the tip becomes bound.

Peak Torque and Revolutions for Quantec .25 Diameter Series

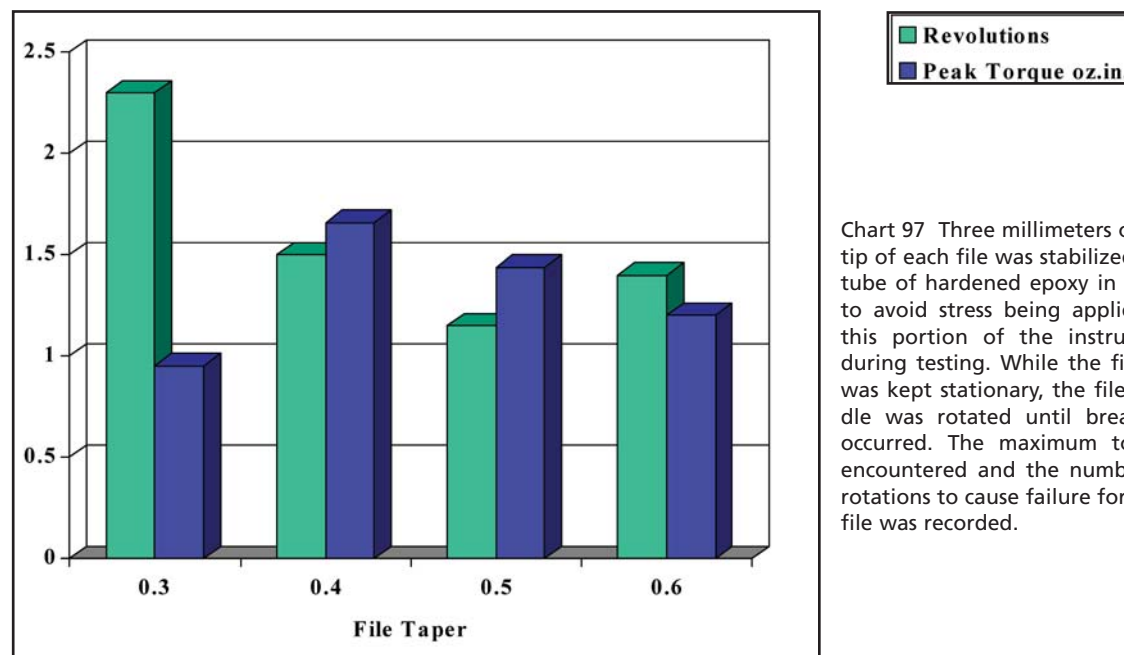


Chart 97 Three millimeters of the tip of each file was stabilized in a tube of hardened epoxy in order to avoid stress being applied to this portion of the instrument during testing. While the file tip was kept stationary, the file handle was rotated until breakage occurred. The maximum torque encountered and the number of rotations to cause failure for each file was recorded.

Torsion strength is closely related to the square of the diameter of files having the same taper. Torsion stress and rotations to failure variations occur with changes in proportions of flute depth and pitch, and other dimensional changes. ***When the tip of the file is bound, torsion failure decreases with an increase in taper only to a point, beyond which the failure increases.*** When file tips of the same size become bound, the file with a larger taper can be more likely to break if the taper is of sufficient size.

Smaller tapered instruments distribute the stress over more of the length of the file whereas the larger tapered files focus more of the stress closer to the tip. On all files tested, breakage increased as the taper increased for files bound at the tip and having larger than a .04 taper. This phenomenon should be considered when following a larger tapered file with smaller tapers, since initial engagement would be limited to the tip.

42. How can the area of engagement be reduced in order to reduce torque?

The engagement of a file can be reduced by shortening the file's working surface, decreasing the number of spirals, decreasing the width of the land, interrupting the contact continuity of the blade, and utilizing file sequencing by changing sizes and tapers during instrumentation so only a part of the file becomes engaged. Although two files may have the same working length, the one with the greater number of spirals will have the greater engagement and require the greater torque to rotate. In addition, the greater the number the spirals in a given length of work-

ing surface, the more perpendicular the cutting edge is to the long axis of the file and the greater the tendency for the file to screw into the canal and thus, more torque is required for rotation.

43. Do any files have shorter working lengths?

Some files have shorter working surfaces specifically for reducing torque requirements. The Light Speed instruments (Light Speed Inc.), having working surfaces ranging from less than 1 mm to 3 mm, are designed around this concept and have the shortest working surface of any of the rotary NiTi instruments. Having much the same configuration of Gates Glidden drills, the working surface is held to the minimum.

All the files in the tapered series of RaCe Files (Brasseler USA) have working surfaces that are 8 mm, as opposed to the conventional 16 mm, for reducing potential maximum engagement and torque by over 50%. The Hero Apical files (Micro-Mega) have working surfaces that are approximately 7 mm in length to provide additional flexibility for the .06 and .08 tapers in addition reducing the engagement. All

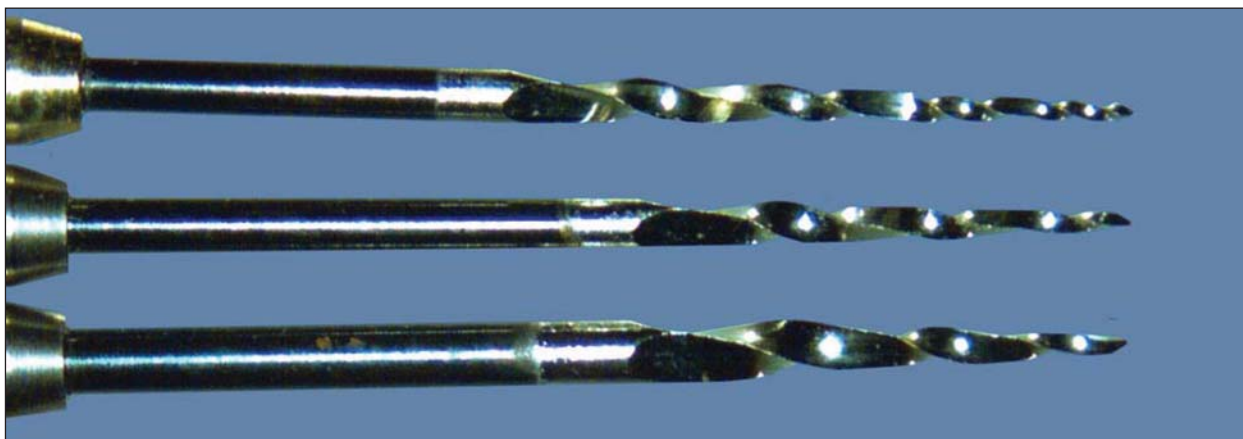


Fig. 98 All of the **RaCe** tapered series have 8 mm of working surface limiting the engagement as compared to conventional lengths.

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the files in the ProFile GT series (Dentsply) have the same tip size and the same maximum diameter that result in different working surface lengths. Consequently, the larger tapered files have the shortest working surface lengths,

while the smaller more vulnerable tapered files have longer working lengths with greater areas for potential engagement. The 20/.04 Profile GT has a 20 mm working length, 4 mm longer than the conventional 16 mm.

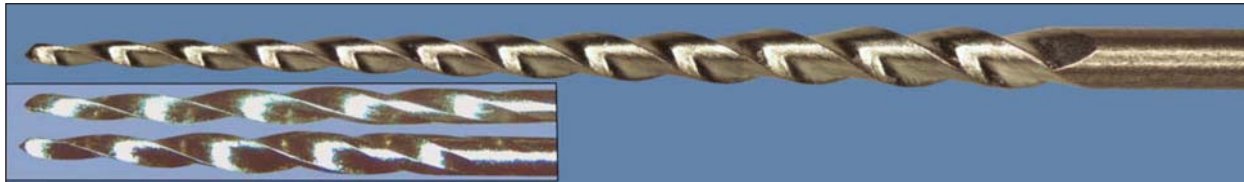


Fig. 99 Micro-Mega Shaper file have 13mm working surfaces (above) and the Hero Apical files have working surfaces that are approximately 7 mm. The Apical files (insert) are available in size .30 mm with .08 and .06 tapers. Note that the shaft diameter is slightly smaller on the handle side of the working surface.



Fig. 100 Since the ProFile GTs have the same tip size and the same maximum diameter, the working lengths vary. The working surface of the 20/.04 is 20 mm, 20/.06 is 13 mm, and the 20/.08 is 10 mm.

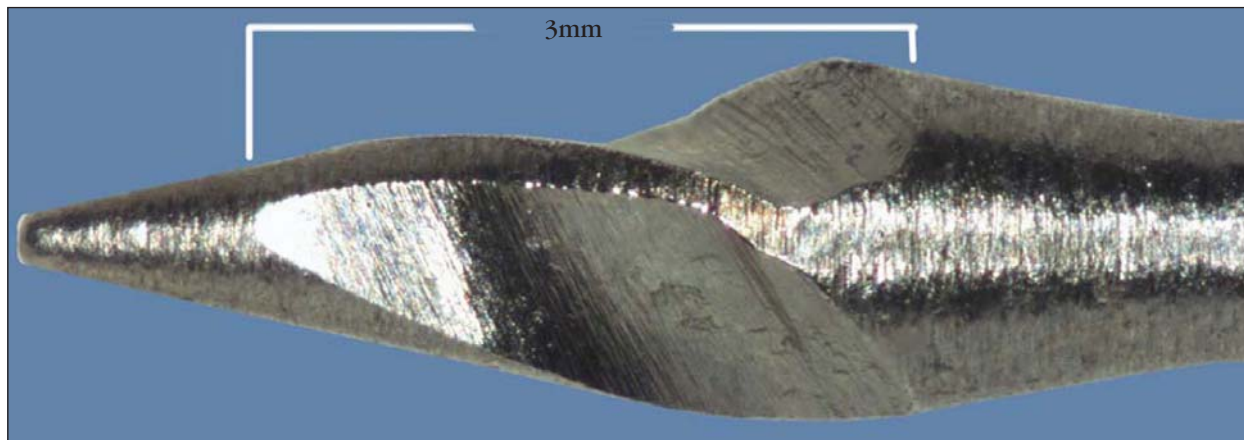


Fig. 101 The Light Speed files have working surfaces that extend no more than approximately 3mm and prepare parallel canals. Since the engagement is minimal, the recommended rotation speed is substantially higher than other files or approximately 2,000 rpm.

44. How does interrupting the continuity of the blade reduce engagement?

Interrupting the continuity of the blade's cutting edge, such as with cross-fissured burrs, can reduce file engagement. With this type of blade configuration, the problem of stress concentration points (disruptions in the uniformity of the stress patterns when there is an abrupt change in longitudinal or transverse cross-sections) along blade irregularities needs to be addressed in order to avoid increasing the probability of file breakage. However, by avoiding abrupt changes in the engagement, stress concentrations can be reduced. Discussed earlier was the Sensor file that had dissimilar helix angles and the flute of one angle intersected the flute of another causing an interruption in the continuity of the blade's cutting edge. These and other means can be used to reduce the blade's engagement and thus, the torque requirements of future files.

Two prototype instruments of particular interest are a broach type file and a cast file. Cloudland Institute, LLC, is developing both files. The broach type instrument eliminates continuous blades and uses a series of individual interrupted scalloped blades on its working surface. The cast file is an amorphous alloy and uses blades each of which encompass only a portion of the circumference of the file shaft

and have helix angles different from adjacent blades.

45. Why are different tapers used?

Employing different tapers can be one of the most important methods of limiting file engagement. The nomenclature, however, for describing the techniques for using tapered files can be confusing to the novice in conceptualizing the action that is occurring if one is only considering an individual file rather than a sequence of files. If a smaller tapered file is inserted into the preparation of a larger tapered canal, only the apical portion of the file initially becomes engaged, yet the technique is termed **crown-down**. On the other hand, crown-down is more meaningful when referring to that portion of the canal being first enlarged during a sequence from large tapers progressing to smaller tapers. Conversely, if a larger tapered file is inserted into a smaller tapered canal, the file initially engages and prepares only the coronal aspect of the canal and yet the sequence technique is called a **step-back** approach. The distinction is important in order to keep in mind which part of the file is being engaged and is being stressed. In either technique, *one advantage in changing from one taper to another is that the initial engagement is minimal and any increase in engagement is gradual, thus enabling an opportunity to more accurately interpret variations in*

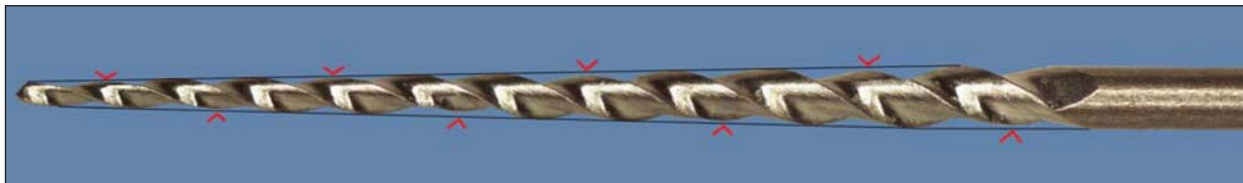


Fig. 102 Interrupting the continuity of the blade engagement can reduce its torsion stress. Note the red arrows indicate that the blade does not extend axially as far in some positions as others. (Cloudland prototype)

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resistance as the file progresses into the canal. That opportunity might not be available when using files having the same taper since this approach can quickly result in full engagement with minimum apical advancement. The operator is better served if progress into the canal is terminated before maximum engagement occurs.

One of the most important considerations for rotary instrumentation is utilizing the advantage of changing file tapers. The reduction of stress on the instruments can

significantly be achieved by minimizing engagement with this technique. When using the crown-down technique, only the file tip, the portion least resistant to torsion failure, initially becomes engaged. When using the step-back technique, a larger diameter, the more torsion resistant portion of the file initially becomes engaged. In contrast, if the canal preparation of one file is followed with a file having the same taper, file engagement is maximized, increasing the torque requirement that increases the stress on the file.

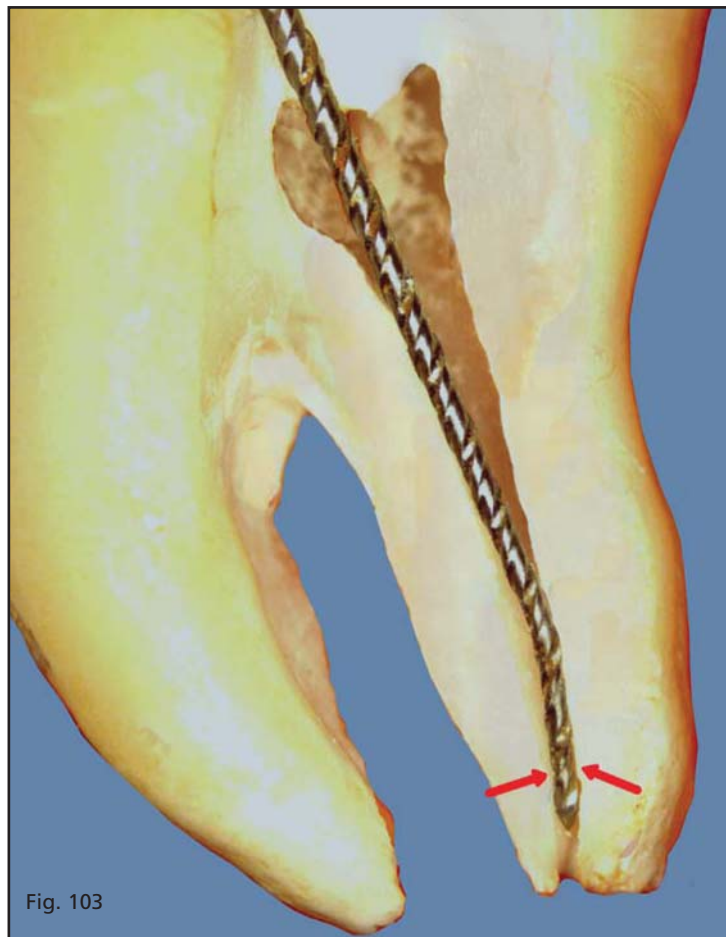
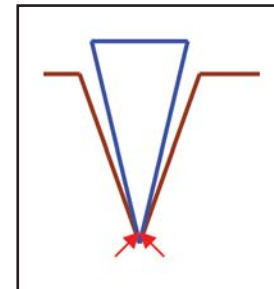


Fig. 103

Small taper inserted into larger taper = crown-down technique and initial minimal apical engagement followed by increasing engagement.



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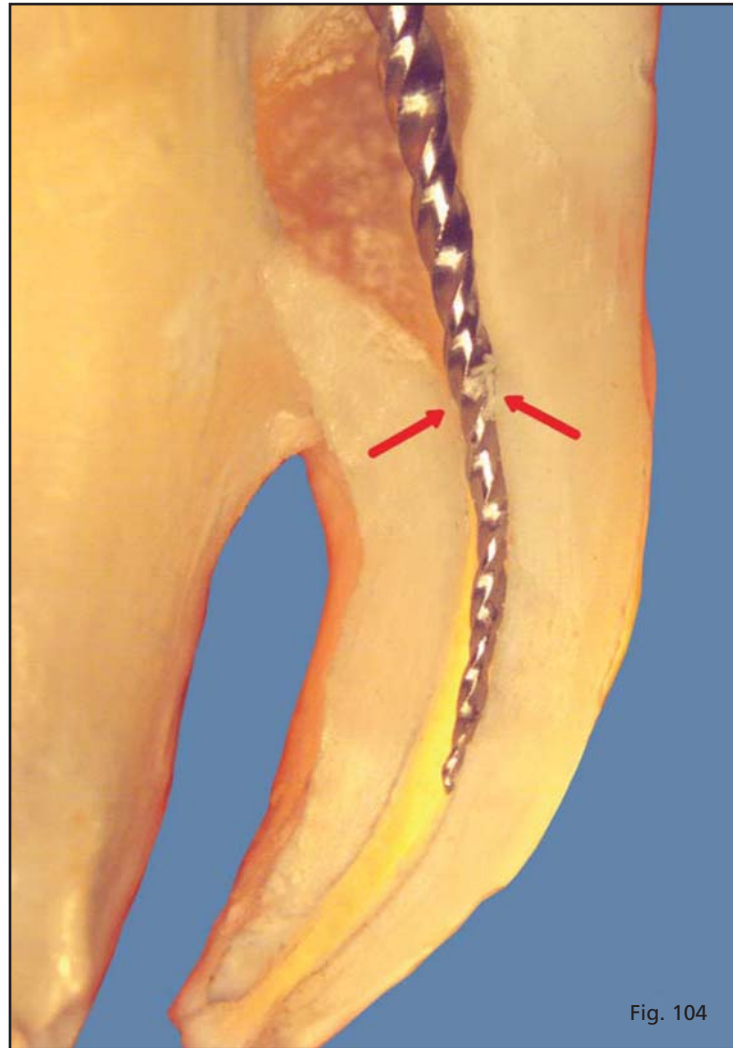
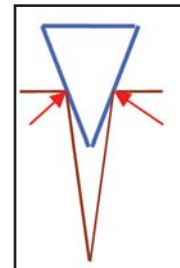
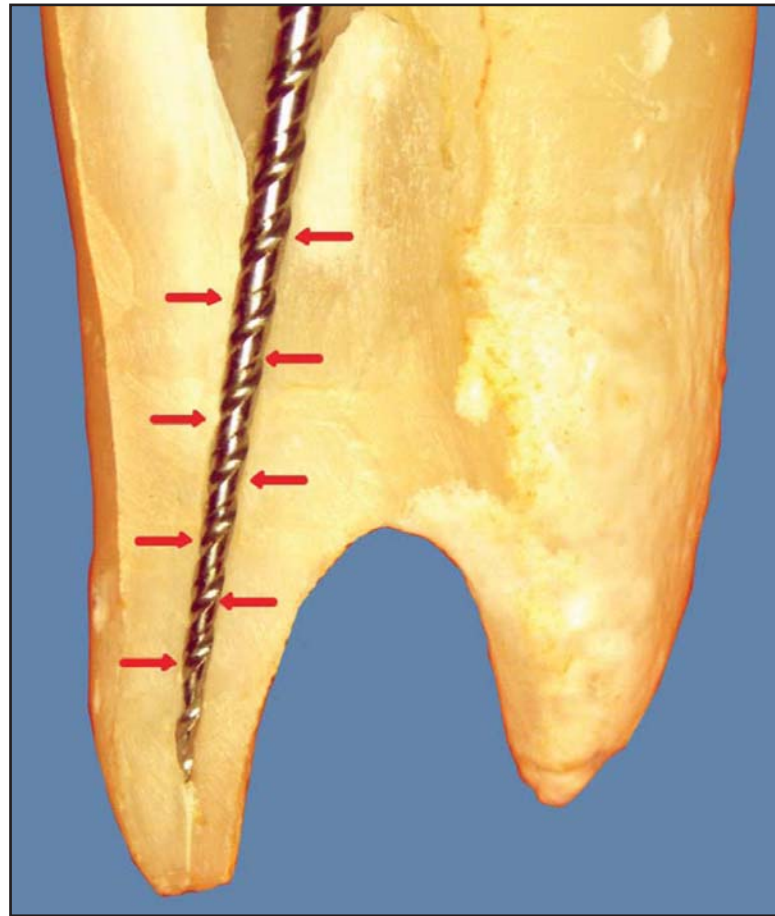


Fig. 104

Large taper inserted into smaller taper = step-back technique and initial minimal coronal engagement followed by increasing engagement.



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File having the same taper as the preparation results in maximum engagement and the possible excessive stress.

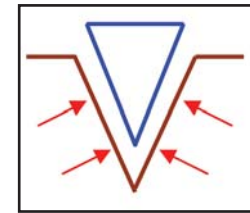


Fig. 105 If a file is inserted into a canal prepared by a smaller file having the same taper, it will immediately become evenly engaged along the full length of the preparation resulting in maximum engagement. If a file is inserted into a canal prepared by a larger file having the same taper, at first only the tip will be engaged. It becomes abruptly engaged for the full length of the preparation when the diameter of the smaller file approaches the diameter of the terminus of the preparation of the larger file. Unlike the technique of changing tapers, maximum engagement can immediately follow minimum engagement with no warning, and the result can be excessive torsion stress on the file. The abrupt change can be prevented if one calculates mathematically the depth at which full engagement will occur and stops before that depth is reached. For instance, if a size 30/.04 taper file is followed by a size 20/.04 file, it will become fully engaged if inserted more than 2 mm.

46. Does changing the sequence of file tapers used change the amount of engagement?

The amount of engagement can be precisely determined mathematically and limiting engagement can be accomplished by the selective sequencing of instrument sizes during instrumentation. An important factor to

remember is the mathematical relationship between the distance the file progresses into the canal and the amount of engagement that occurs. Many dentists erroneously assume that the amount of engagement equals the depth of insertion. Consider the engagement that occurs when a size 25/.04 taper file extends the preparation of a 25/.06 file only 2 mm as illustrated below:

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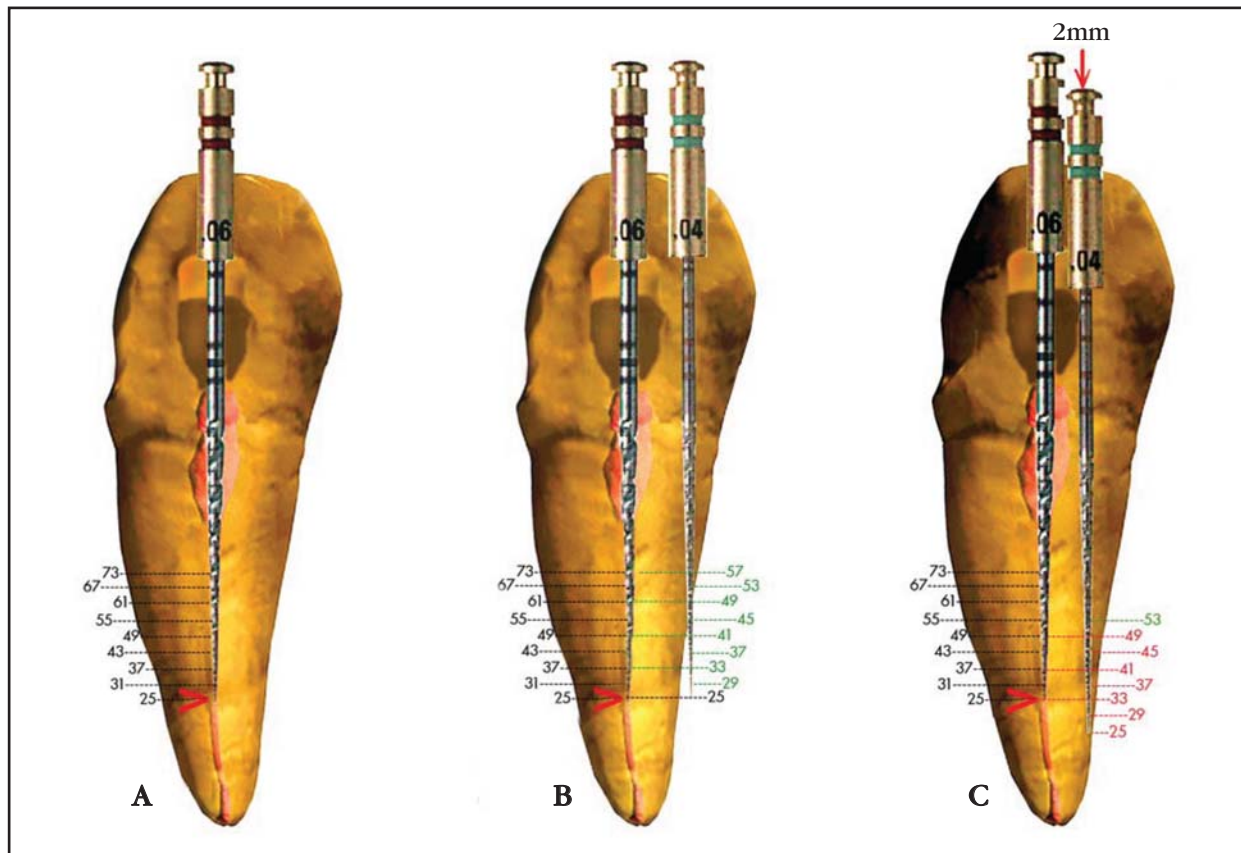


Fig. 106 Extending the preparation of a file with a subsequent file having a smaller taper, results in an increase of engagement that is greater than the increase of the length of extension. If the canal is prepared with a 25/.06 file to a depth illustrated in image A and is followed with the insertion of a 25/.04 file illustrated in image B, only the tip of the 25/.04 will engage the terminus of the preparation and the remainder of the file will be smaller than the preparation. If the 25/.04 file advances only 2 mm beyond that pointing image C, 7 mm of the length of the file becomes engaged at its tip portion. If the sequence is reversed and the 25/.06 file is inserted into the preparation of the 25/.04 and advanced 2 mm beyond the point of contact, all of the working surface of 25/.06 file becomes engaged to the orifice of the .04 preparation. This method for determining engagement assumes that the canal was smaller than the file used before enlargement.

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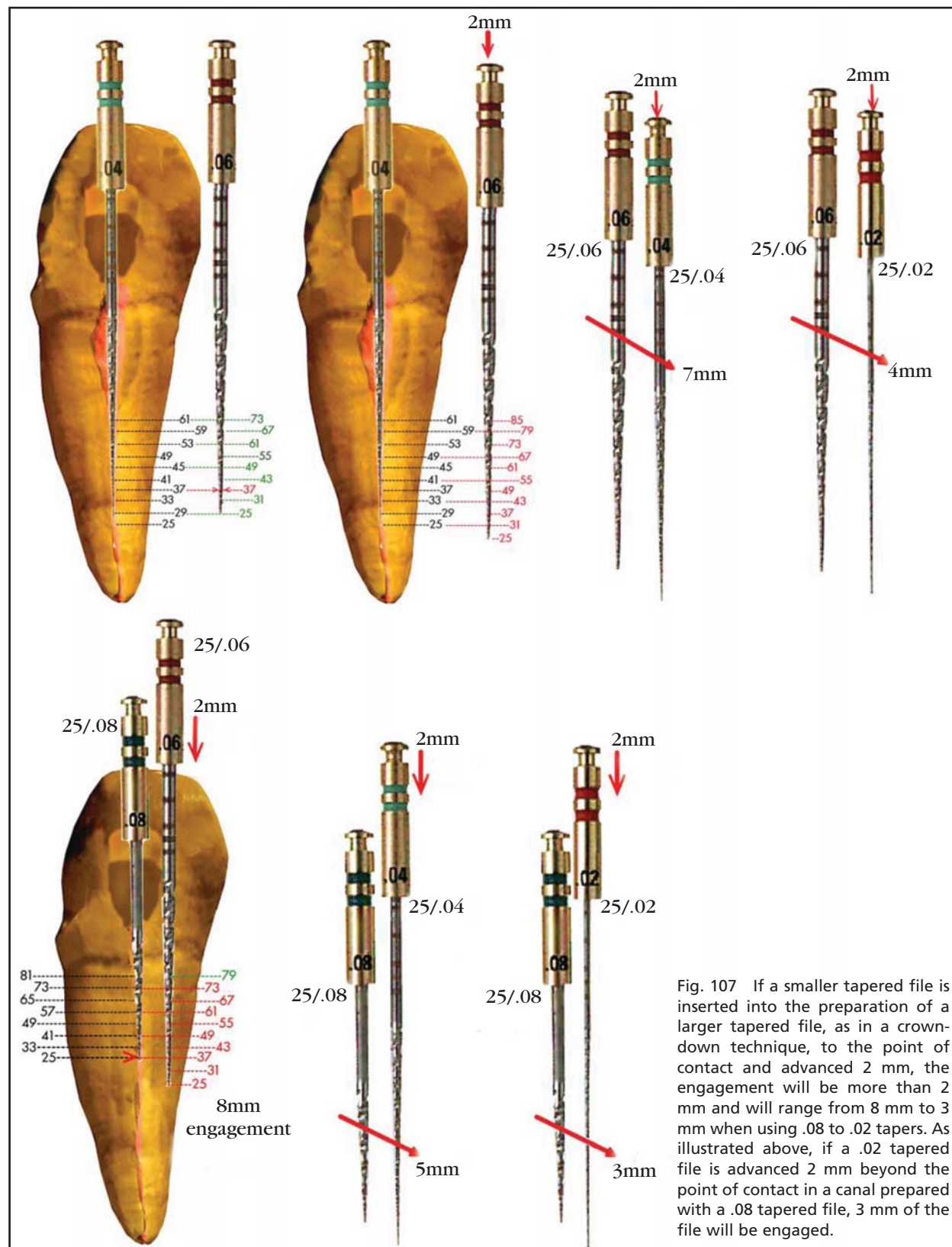


Fig. 107 If a smaller tapered file is inserted into the preparation of a larger tapered file, as in a crown-down technique, to the point of contact and advanced 2 mm, the engagement will be more than 2 mm and will range from 8 mm to 3 mm when using .08 to .02 tapers. As illustrated above, if a .02 tapered file is advanced 2 mm beyond the point of contact in a canal prepared with a .08 tapered file, 3 mm of the file will be engaged.

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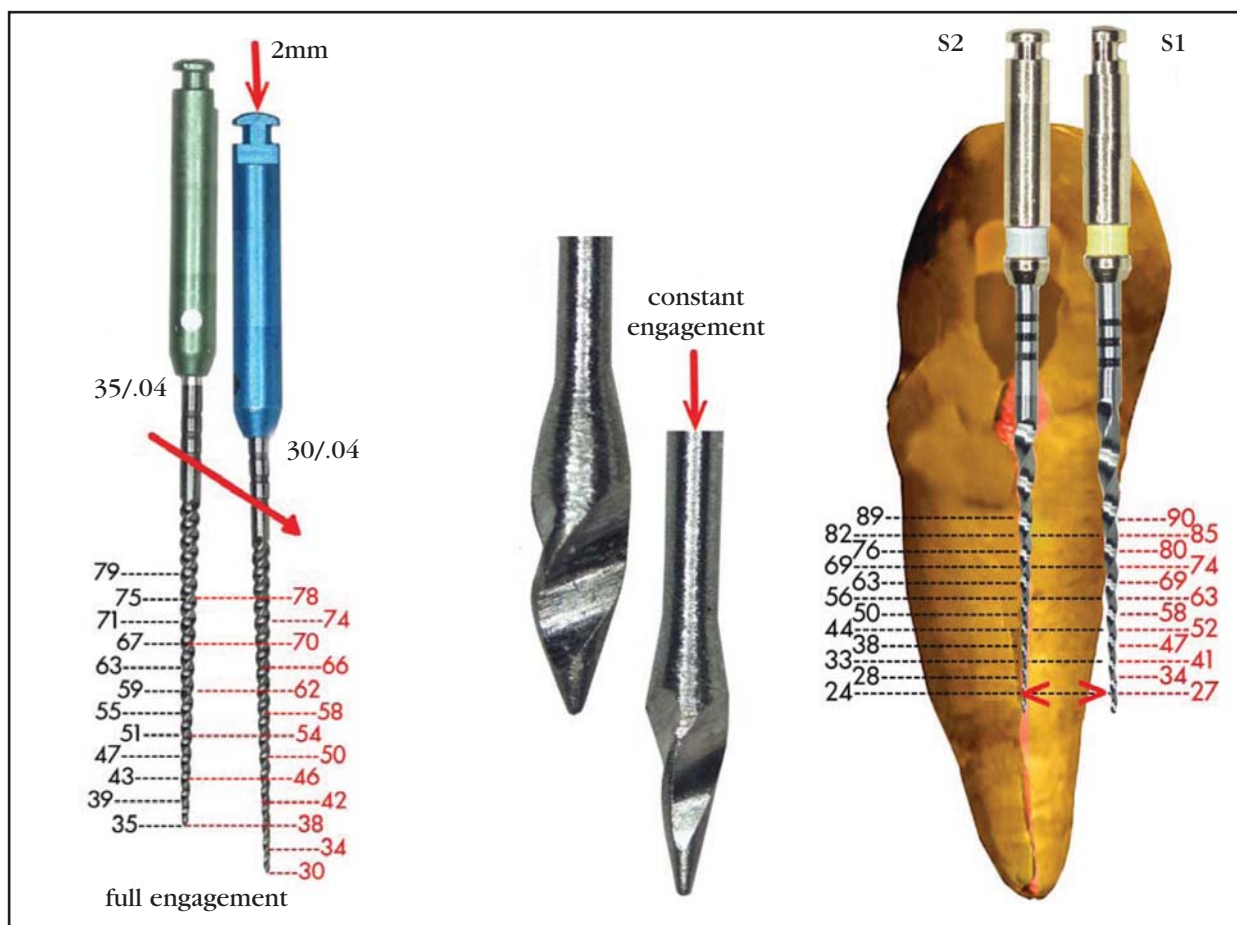


Fig. 108 If a larger file is inserted into the preparation of a smaller file, having the same taper as in a step-back technique, the larger file immediately becomes fully engaged for the length of the preparation. If a smaller file is inserted into the preparation of a larger file having the same taper as in a crown-down technique, at first only the tip will become engaged until the terminus of the preparation is met and then the file immediately becomes fully engaged for the length of the preparation. If a Light Speed file is advanced into a canal, its engagement is limited to its working surface.

The Protaper files have multiple tapers along their working surface and engagement cannot be easily calculated mathematically. Engagement can be determined with sliding scales by superimposing the dimensions of the first file with the following file. As illustrated, if a F1 file is advanced to the same depth as the S2 file as recommended by the manufacturer, 12mm of the file becomes engaged.

When using files having the same taper, an abrupt change can occur in the amount of engagement with a minimum amount of additional advancement into the canal. For example, if a canal has been prepared to a size 40/.04 taper, a size 35/.04 taper file can prepare the canal to a 1 mm greater depth and only the apical 1 mm of its tip will become engaged. Any greater depth of

advancement can cause the entire working length of the file to become simultaneously engaged and the torque required for rotation may be more than necessary to break a the tip if partly bound. Tactilely determining when minimum engagement changes to maximum engagement can require more time than is necessary in order to avoid file separation and is best determined mathematically.

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47. Does the location of a curvature make a difference in choice of technique?

As stated previously, the ability of a file to resist fatigue has an inverse relationship with the square of its diameter. The flexibility of the file has the same inverse relationship; therefore, the smaller diameter tip portion of a file can negotiate an apical curvature easier than the larger diameter portion can negotiate the same amount of curvature in the coronal or mid-root part of the canal.

The radiographic appearance can seem straight mesio-distally while having curvatures buccal-lingually. Determining the canal curvature is of paramount importance for

preventing fatigue failure. Inserting a file smaller than the canal without rotation and determining if any resistance is met, can indicate the presence and location of curvatures. The amount of resistance can be an indication of the abruptness or radius of the curvature or it can be an indication of the file diameter. In either case, applying pressure to negotiate the curvature increases the stress the file undergoes. Testing seems to indicate (as seen in section 4) that there is a critical pressure to negotiate curvatures that leads to fatigue for all diameters. Determining a safe pressure that can be applied is somewhat subjective, but applying more than 450 g., approximately 1 pound, seems to result in an unacceptable amount of failure.

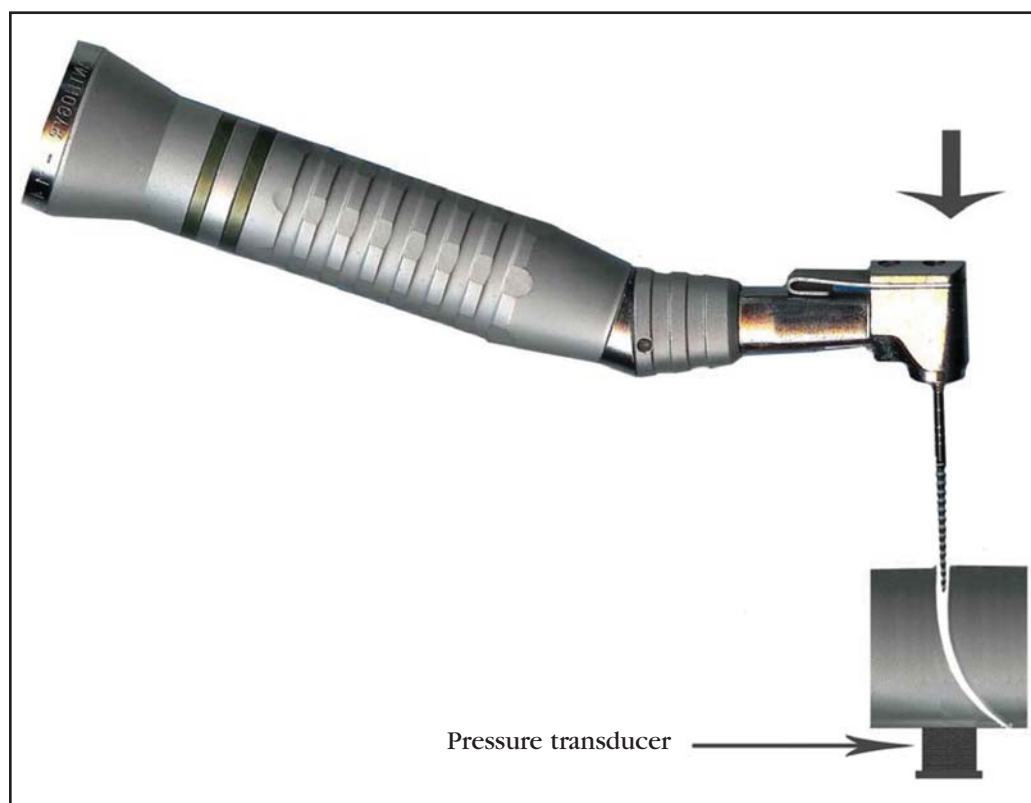


Fig. 109 Rotating at 300 rpm, each file progressed into a metal block having an open canal with a 45-degree curvature having a 8 mm radius. The file's resistance to deflection, or the pressure exerted on the file to passively negotiate the canal, was measured. When the required pressure exceeded 450 g., the incidence of breakage became significant. Measurements below this amount were subjectively referred to as being in the comfort zone or requiring a force less than would ordinarily result in breakage.

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This graph charts the pressure an unengaged file, in a 45-degree curvature with an 8 mm radius, exerts on the canal when D9 for each file of the Quantec and ProTaper Series was advanced to the mid-point of the curvature.

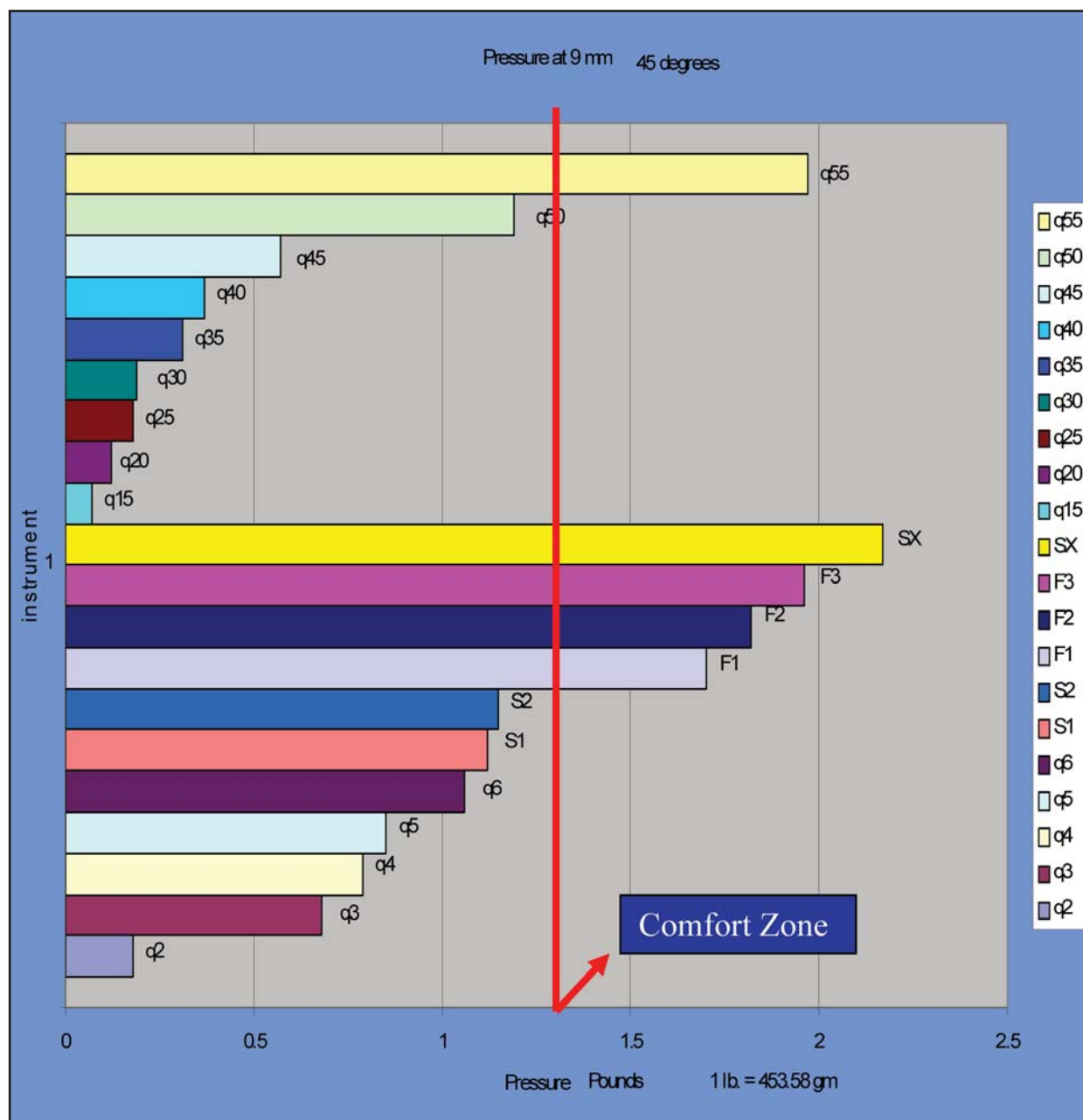


Chart 110 Quantec Series = q15 (size 15/.02 taper) to q55 (size 55/.02 taper) and q2 (size 25/.02 taper) to q6 (size 25/.06 taper). ProTaper Series= SX, S1, S2, F1, F2 and F3.

Of the Quantec .02 tapered series, the Quantec 50/.02 and the 55/.02 required more than 450 g.

Of the Quantec greater tapered series, the 25/.06 file required more than 450 g.

All of the Protaper files required more than 450 g.

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Calculating the diameter of a file at the point of curvature helps in determining the possibility of file breakage or canal transportation. If the curvature of a canal is acute or compound, larger less flexible file diameters are more likely to transport the canal due to rigidity or fail, since fatigue is related to the square of the diameter. ***The location of the curvature is as important as the severity of the curvature.*** A severe apical curvature can be less threatening than a more moderate more coronal curvature.

Although there are no studies indicating the most frequent cause of breakage, failure at larger diameters is commonly the result of fatigue in curved canals. Studies included in Section IV have demonstrated that if

the file diameter at the point of curvature is in excess of 55/.02, 50/.04, 45/.06, or 35/.08, failure becomes a risk if any appreciable torque is applied. Although a considerable amount of interest has been shown for determining precise torque and fatigue limits, it must be remembered that these limits are statistical quantities and substantial deviations can be expected. Any discussion of torque limiting handpieces, comfort zones, or margins of safety are far from exact and only represent estimates in probability determined by testing relatively few specimens. However, sufficient numbers of failures merit modifying techniques to avoid exceeding the suggested limits.

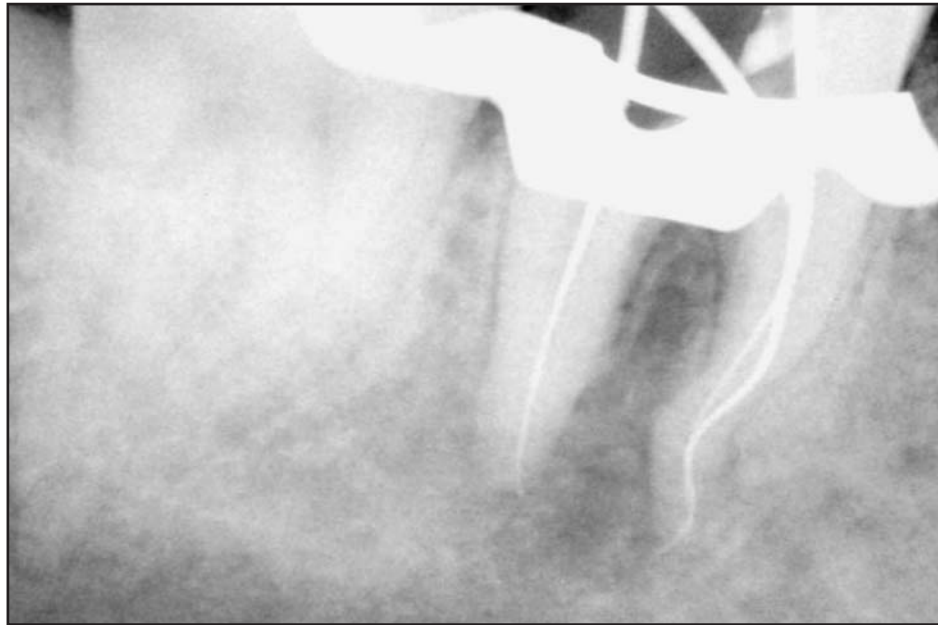


Fig.111 **G. Matthew Brock**

Compound curvatures in the mid-root and uncertainty of the root inter-proximal anatomy can limit the use of larger file sizes and tapers. These curvatures can be precariously close to the periphery of the root and the possibility for perforations should be considered before routinely graduating to larger tapered files.

48. Is the crown-down always advantageous over the step-back technique?

Using the larger diameters of the crown-down technique for canal preparation can be a problem for coronal or mid-root curvatures and is used most beneficially to a depth short of any substantial curvature.

Once a severe curvature is encountered, smaller diameter files used in the step-back technique apical to the curvature can minimize instrument stress and canal transportation. By inserting non-rotating files with smaller diameters around curvatures and with-drawing with rotation, the severity of the curvature can be easily determined while avoiding excessive stress.



Fig. 112 If two files have the same tip diameter, the file with the larger taper will more likely transport a curved canal.

A larger file will undergo excessive stress or will likely transport the canal as it progresses around the curvature. The excessive file stress or canal transportation can be prevented by first enlarging the canal with a smaller instrument to determine technique and file diameter limitations. The difficulty of negotiating the canal with a larger instrument becomes apparent. Although abrupt mid-root and coronal curvatures are not common in the mesio-distal plane, they frequently occur in the buccal-lingual plane.

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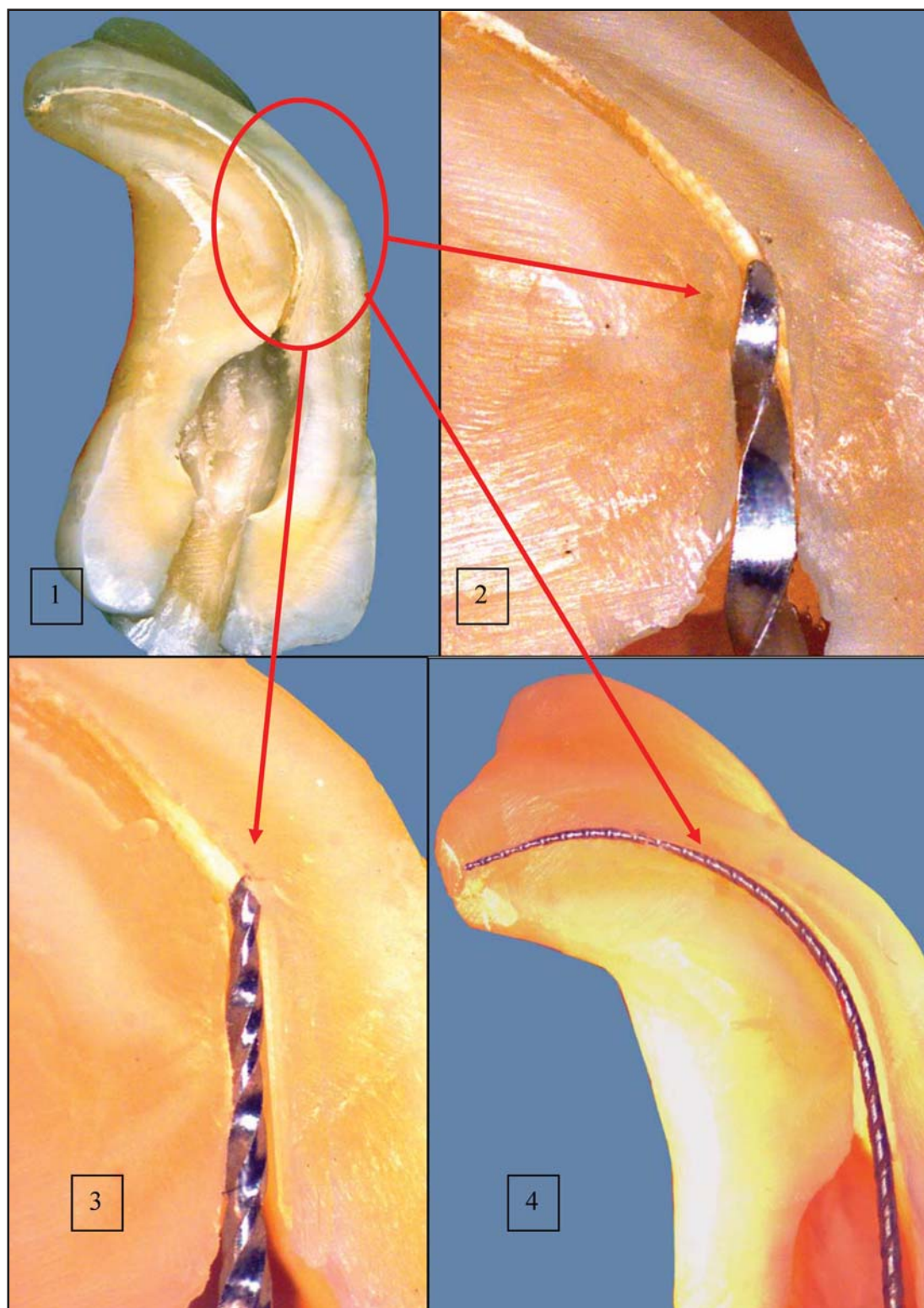


Fig. 113

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Fig. 113

Image 1 illustrates a canal that has straight-line access. It also has a coronal curvature that presents a problem for large file diameters causing a ledge in the canal wall or exerting undue stress on the file.

Image 2 illustrates the resistance a file with a large taper and diameter (in this case a 40/10) would meet at the point of curvature. The resistance can be determined tactilely by requiring more pressure in order to advance the file to a greater depth. Applying more pressure for advancement can cause ledging or file breakage.

Image 3 illustrates the same problem depicted in image 2. The routine graduation in the reduction of diameter and taper (in this case a 25/06) as recommended in the crown-down technique can complicate instrumentation. The point of curvature can represent a point for calculating the diameter of a file as it advances beyond this position.

Image 4 illustrates the selection of a file with a small diameter at the point of curvature in order to reduce potential file stress and canal transportation. Once a smaller size and tapered file reaches a position beyond a curvature, the position of initial engagement of any subsequent larger file and its potential stress can be determined mathematically. For instance, if the canal illustrated above is 16 mm to the apex and a 40/10 file is carried 6 mm into the canal to a point of curvature followed by a 15/02 file that is carried to the apex, a 25/04 file can be advanced 10 mm into the canal until its initial engagement. The position of its engagement will be 4 mm from its tip at its .41 mm diameter and 4 mm of its tip will be passive. In following a gradual crown-down procedure, no such determinations can be made and avoiding canal transportation or file breakage is a function of the instincts of the operator.

Apical curvature

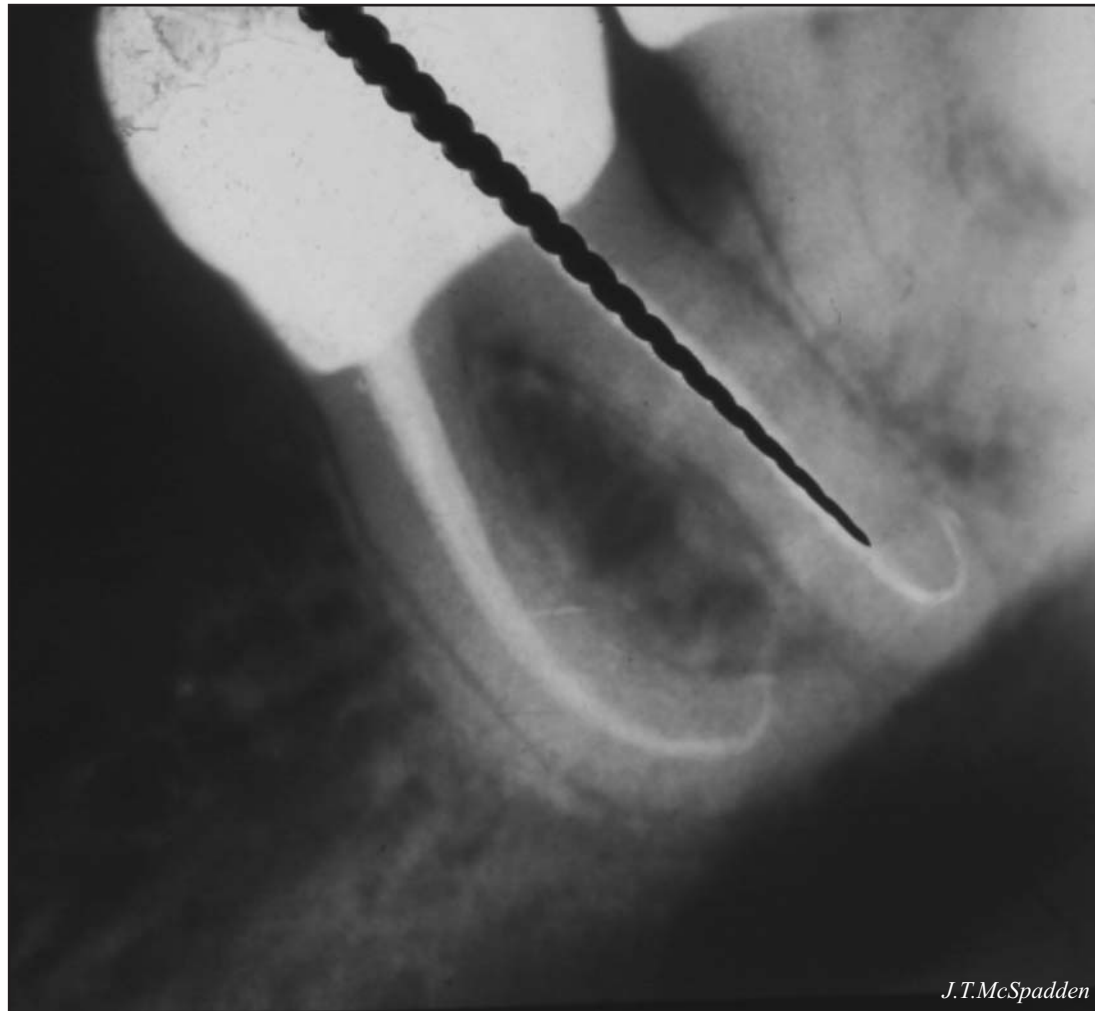


Fig.114 A 20/06 file, superimposed on the radiograph, illustrates a case reasonably suited for the crown-down technique if a buccal-lingual curvature is not a limiting factor. As the working length is approached, smaller tapers with greater flexibility are used to instrument the severe apical curvatures.

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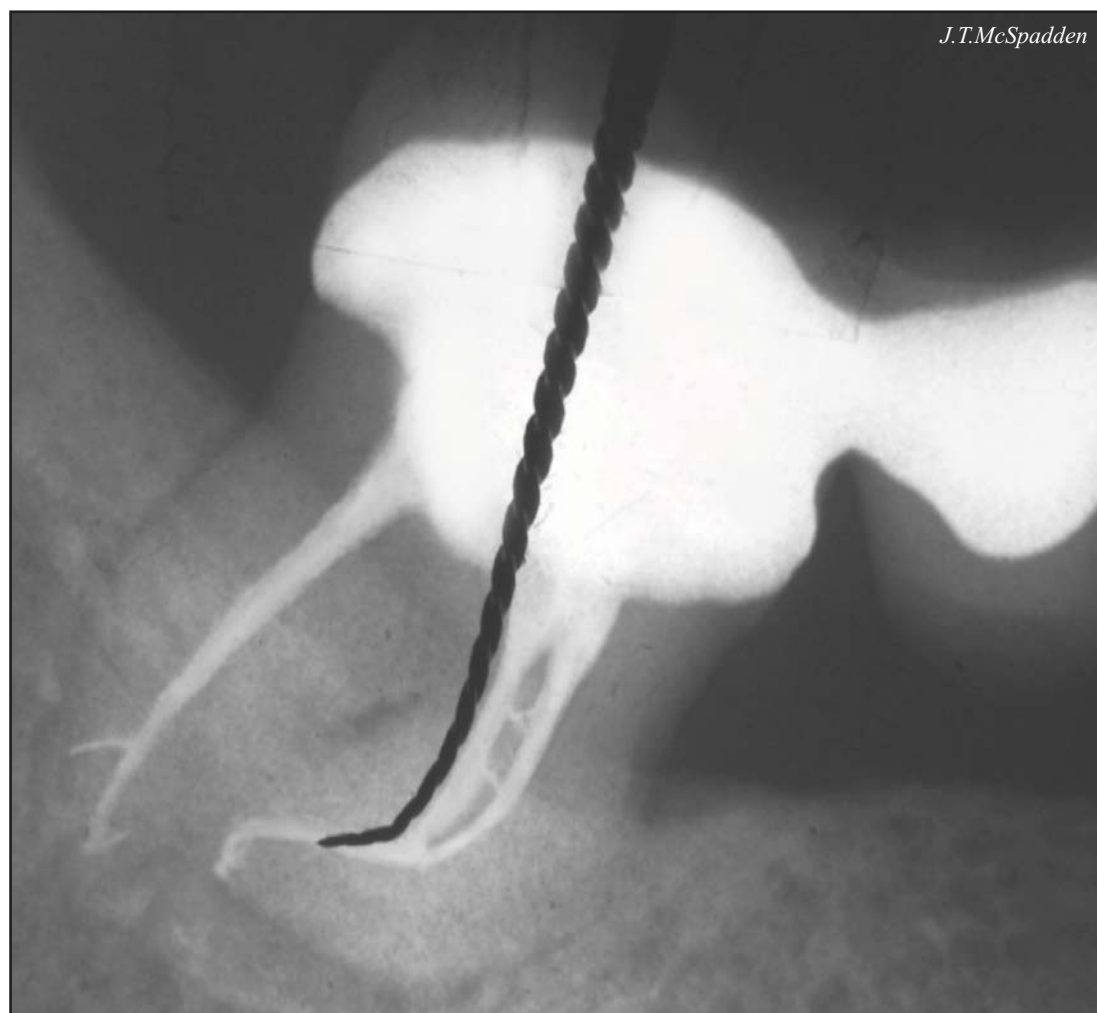
Mid-Root curvature

Fig. 115 The radiograph with a superimposed 20/06 file illustrates that caution must be exercised if the crown-down technique is to be used apical to the curvature while avoiding canal transportation or undue stress on the file. The step-back technique might be a more judicious approach, as curvatures in the facial-lingual plane are not apparent. The operator must interpret the resistance encountered in each portion of the canal in order to determine the appropriate instrument sequence. The threat of excessive file stress may be more difficult to determine when the curvature is gradual as the increased pressure and torque required to advance into the canal is also gradual.

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Coronal Curvature

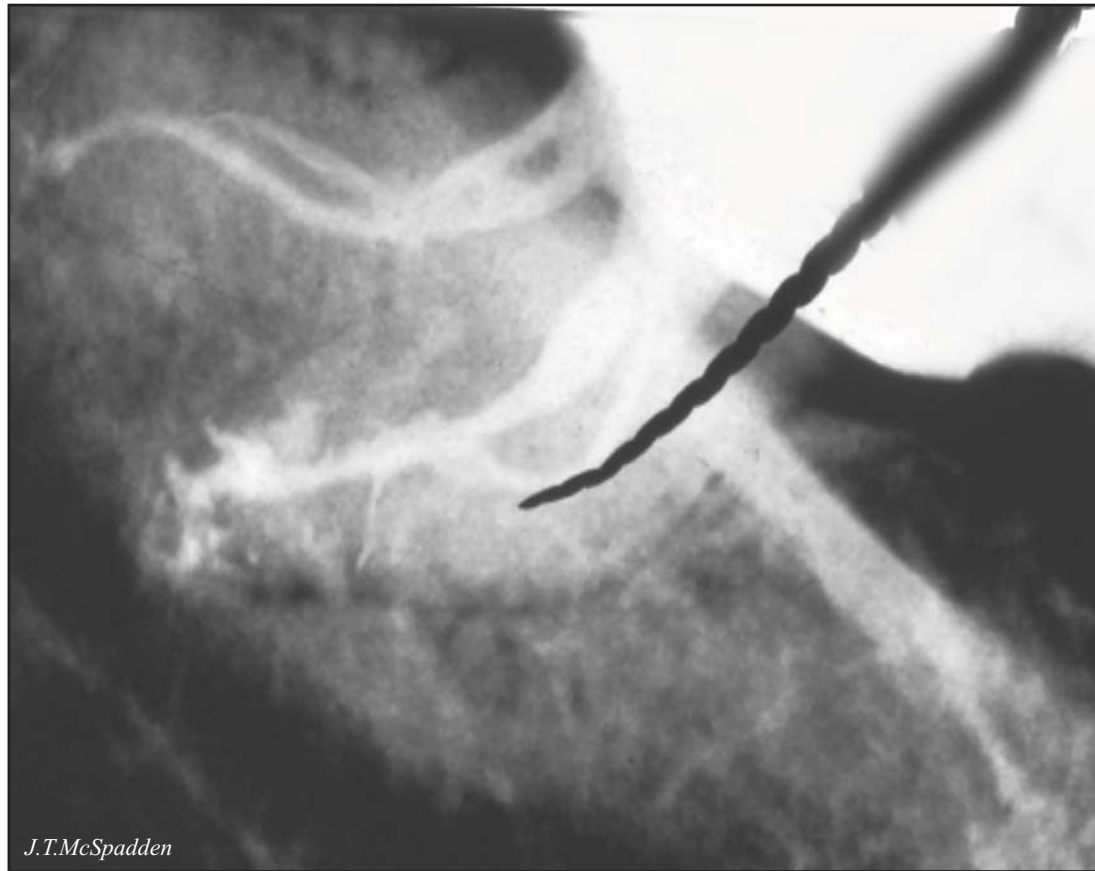


Fig. 116 Superimposed on the radiograph is the apical portion of a size 20/.06 taper file. The crown-down approach in coronal curvatures can cause unnecessary stress on the file or canal transportation if carried beyond an acute curvature when orifice relocation compromises the tooth or does not eliminate sufficient curvature.

49. Is there a basic technique that I can follow?

Evident in the preceding discussions are the interrelationships of file dimensions. Although developing expertise in using rotary instrumentation depends upon a thorough understanding of these relationships, the first attempts at putting them all together can be confusing and a cause for returning to a technique with a definite standard sequence. Basic technique recommendations

can be established that encompass all the considerations of file design and sequencing relationships but the results can be very different from those that are currently advocated. No procedure should be considered as an absolute rule but should be a consideration based on understanding. The following section attempts to reduce file relationships to steps of considerations that can be followed as a procedure. Each step should be consistent with logic and compared with customary procedures before being followed.

Section III. Mastering the technique

50. Are there any rules or considerations in following a technique?

As emphasized at the beginning of this book, the purpose of the research presented is not to provide a regimented “cookbook” technique, but to provide a rationale for approaching and solving the problems of instrumentation. The result of following the rationale is the formulation of a technique, but one more adaptable to problems. Otherwise, research would amount to little more than academic exercise. In examining the results of research presented throughout this book, trends become apparent for designing instrumentation procedures. The primary consideration is to set parameters for preventing file failure and eliminating unnecessary or counterproductive actions. By observing the situations that usually have a high incidence of file separation, we can then test procedures to effectively avoid those situations. Once effective procedures are identified, then the most efficient approach can be determined. The incidence of file failure during testing indicates instrumentation should encompass considerations for all of the following parameters for rotary instrumentation:

1. Select the **tip design** that will not burnish or transport the canal.
2. Advance a file into the canal with no more than **1 mm increments** with insert/ withdraw motions.
3. To advance a particular file the first 1 mm into a canal after it becomes engaged, a minimal **specific pressure** needs to be applied. If that pressure needs to be increased in order

for additional advancement to occur or if a negative pressure (screwing-in force) is encountered, change to a different tapered file or circumferentially file coronal to this position.

4. File advancement into the canal should be able to occur at a rate of **at least ½ mm per second** without increasing the pressure for insertions.
5. If a file has more than a .02 taper, do not advance more than 2 mm beyond the preparation of the previous file if any part of the file is engaged in a curvature.
6. Except for .02 tapered files having a size diameter of .20mm and smaller, **do not engage more than 6 mm** of the file's working surface if the file is engaged in a curvature.
7. Apply **no greater than 1 pound of pressure** on any file while advancing into the canal.
8. Beyond a the point of curvature in the apical zone, the file diameter should be **no greater than .60mm for a .02 taper, .55mm for .04 taper, .50mm for .06 taper, and .35mm for a .08 taper.** (This consideration is the result of testing for 45-degree curvatures having 8 mm radii and applies only to these dimensions for rotary NiTi files. File diameters should be smaller for more severe curvatures and can be adjusted larger for less severe ones.)

When any of the parameters cannot be met, changing to a file having a different taper in the technique sequence will usually enable re-adherence to the parameters. These parameters, by necessity, require subjective and arbitrary judgments, since there is no one point at which file breakage definitely occurs or definitely does not occur. However, careful

examination during extensive testing indicates that any exception to these parameters should be undertaken with the cautious awareness of the operator. Most of the testing for determining how large a file diameter could be used in a canal was done on 45-degree curvatures with 8 mm radii. Although somewhat arbitrary, curvatures of this magnitude and location are found in molars with a frequency to assume their presence unless determined otherwise. Admittedly, the selection of this particular curvature as a standard for testing is subjective, but the immensity of anatomical variations, and the insignificance of sample sizes compared to the total numbers of teeth in the adult population, require some arbitrary judgments. In a survey of the frequency of curvatures, the results of Schafer et al, (JOE, Roentgenographic Investigation of Frequency and Degree of Canal Curvatures in Human Permanent Teeth) indicated that of the mb2 canals in maxillary first molars examined, the median degree of curvature was 42 degrees with a 6.6 mm radius when viewed from the buccal and 14 degrees with a 9.2 mm radius when viewed from the mesial. This curvature is substantially greater than the standard selected for testing. Eighteen percent of these canals had compound curvatures, s-shaped canals. Files with larger diameters than the ones recommended

for the 45-degree curvatures might be considered for less severe curvatures and smaller diameter files considered for more severe ones. Although mathematical extrapolations can provide close approximations of diameter limitations, even an awareness of the concept can facilitate the operator's judgment. **A thorough understanding of this concept probably contributes to the development of expertise for instrumentation more than any other.**

51. What length of each file can be advanced beyond a curvature having a 45-degree curvature with an 8 mm radius?

A visual representation of each file size and taper that can be carried around a 45-degree curvature with an 8 mm radius while considering the above listed parameters, can help visualize the limitations of file advancement during instrumentation. *Note that even though there has been a trend to eliminate .02 files from technique routines, their use can be extremely beneficial for instrumenting to working length in canals that have coronal or mid-root curvatures, and step-back techniques can become advantageous approaches for these anatomies.* Also note how any increase in file tapers increases their limitation in coronal and mid-root curvatures.

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In the following illustrations of each tapered file series, the portion of the file shaded in red indicates that diameter of the file that should not be advanced beyond a 45-degree curvature having an 8 mm radius. The diameters that should not be exceeded are a .60 mm for a .02 taper, a .55 mm for a .04 taper, a .50 mm for a .06 taper and a .35 mm for a .08 taper.

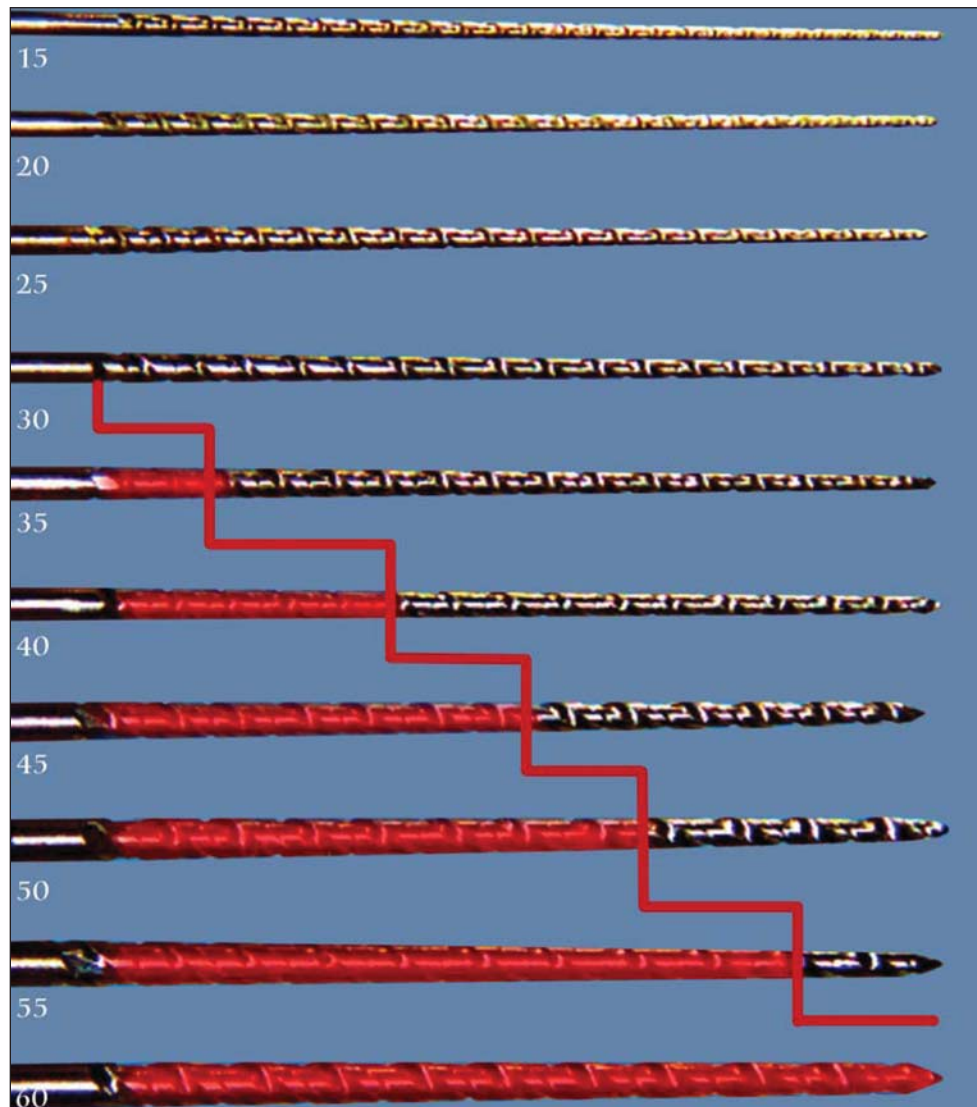


Fig. 117 **.02 Taper Series**

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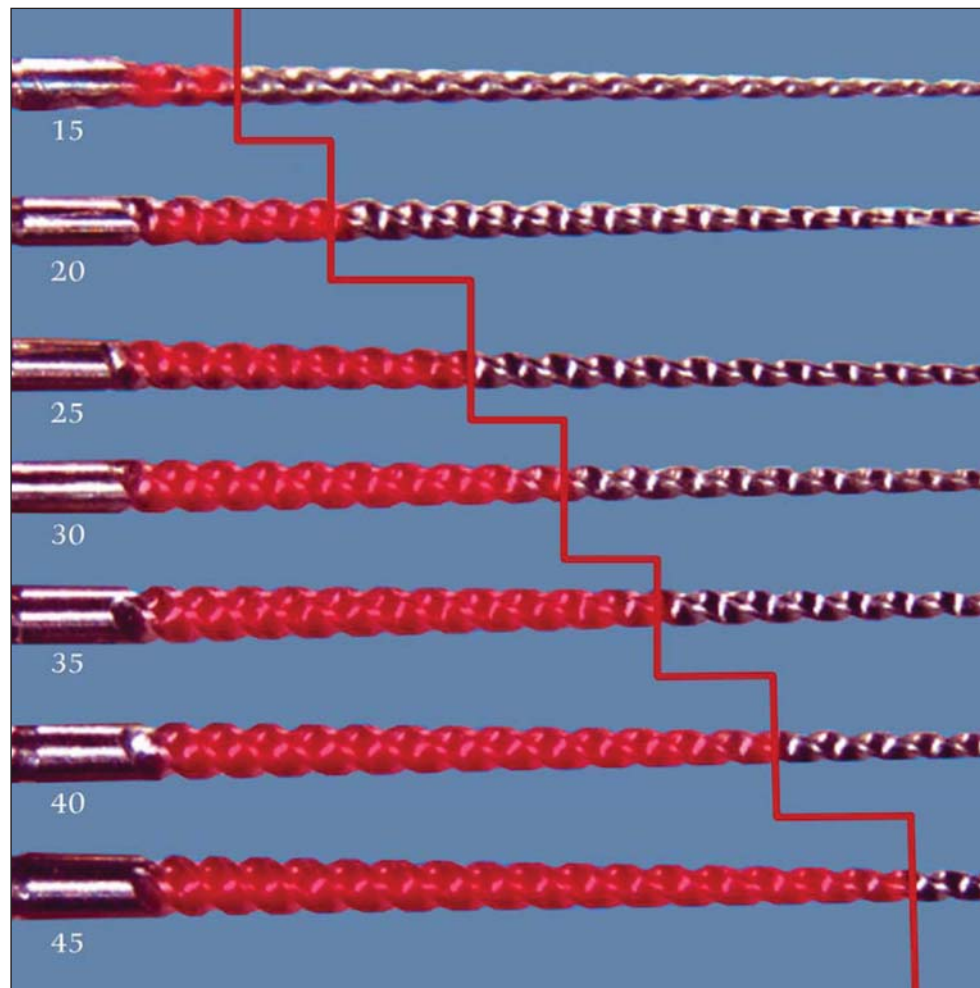


Fig. 118 **.04 Taper Series**

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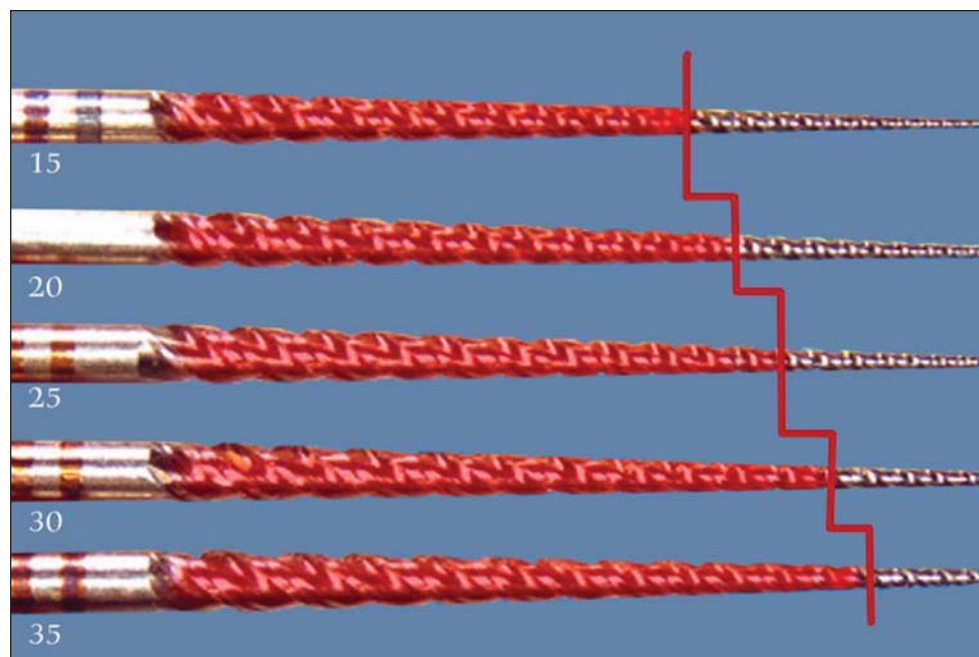


Fig. 119 .06 Taper Series

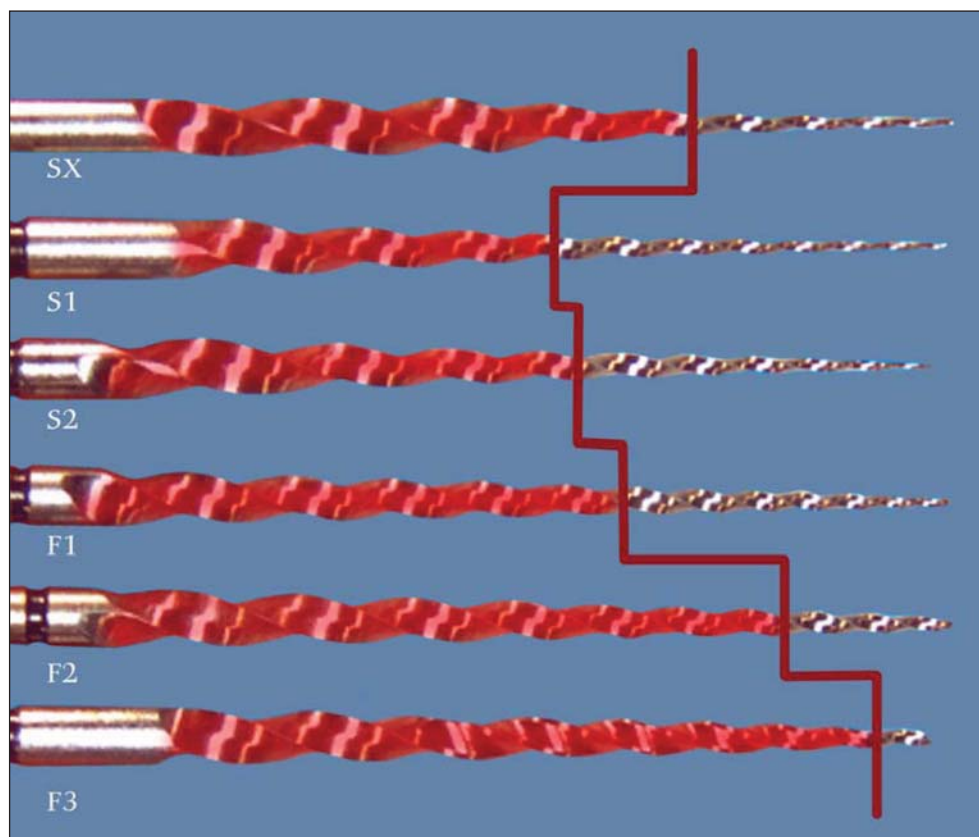


Fig. 120 ProTaper Series

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Since stress on a file is inversely related to the radius of curvature and related to the square of the file radius, mathematical extrapolation of the diameters that should not be advanced around a 45-degree curvature with an 8 mm radius, can provide an approximation of the file diameters that should not be advanced around other curvatures. Examination of the extrapolations indicates that increasing the curvature radii might not appreciably increase permissible file diameters as one might expect for the prevention of file failure.

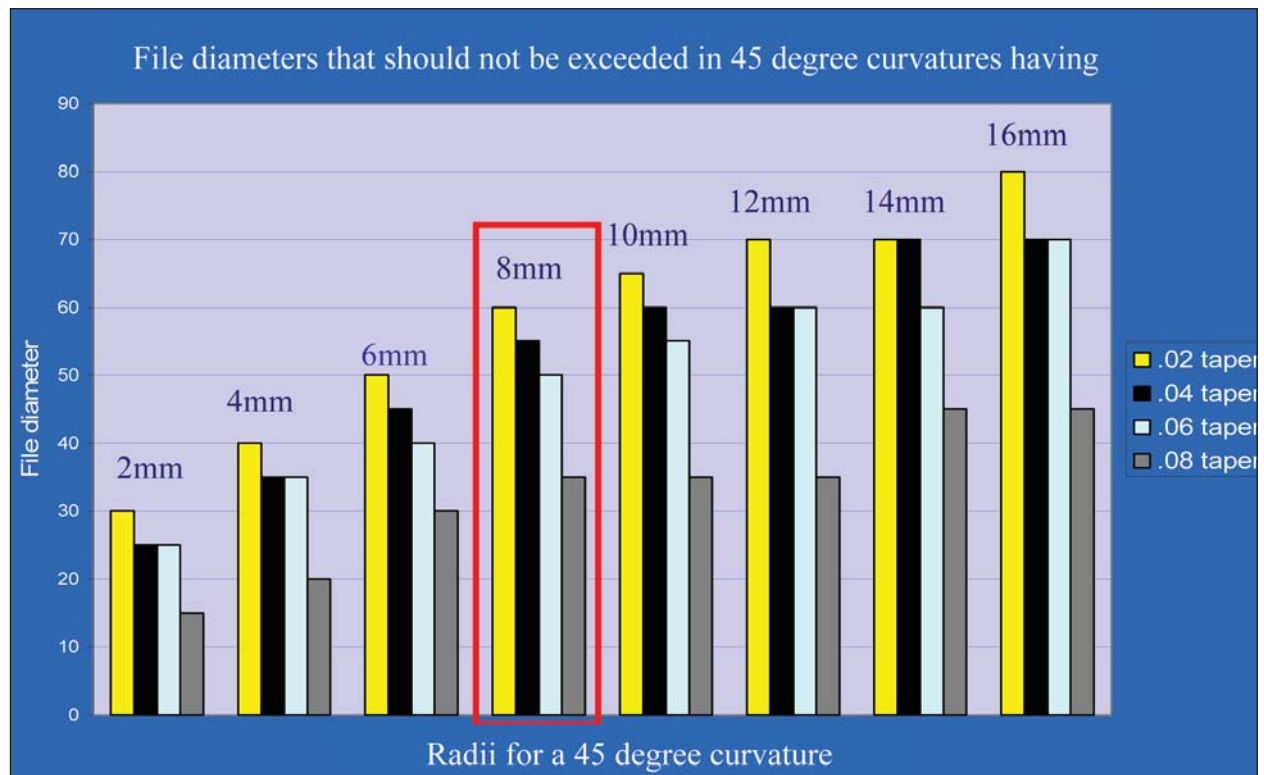


Table 121 Assuming the file diameters of different file tapers should not be exceeded in a 45-degree curvature having an 8 mm radius (outlined in red), the values for file diameters that should not be exceeded were extrapolated and charted for canals having 45-degree curvatures with different radii.

Although many of the accepted instrumentation techniques encompass few, if any, of the parameters listed above, working within the parameters can be done with impressive efficiency, because minimum file stress is maintained. Each step of instrumentation can occur quickly without repetitive non-productive attempts. Following the parameters should provide the means to advance into the canal ½ mm per second with each file insertion. The elimination of the less productive and more threatening procedures expedites results. Even though more files may be used, the total cumulative time can be extremely impressive when compared to other techniques. For reasons of safety and expediency, all the techniques illustrated in this book follow procedures that conform to these considerations. While following these procedures, one should keep in mind the purpose is to illustrate a means for maximizing efficiency for enlarging the canal space while minimizing instrument failure—not to advocate a particular canal size or taper. The final canal dimensions should be adjusted to conform to the judgment of the operator and the requirements of the obturation technique used.

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52. Can a division of the canal into zones of preparation be beneficial?

If all of the parameters listed above are to be followed, dividing the canal into two zones can simplify and expedite canal preparation, with each zone having a different technique approach. These zones are most effectively differentiated by the location of curvatures or constrictions, which result in peaks of increased torsion or pressure during advancement into the canal. Two methods are very useful in identifying a restriction: (1) If a file that is smaller than the canal meets resistance as it is passively advanced into the canal, the depth at which the resistance is met also denotes the terminus of the

coronal zone. (2) To advance a .06 tapered, .25 mm diameter file the first 1 mm into a canal after it becomes engaged, a specific pressure needs to be applied. If a depth is reached in a canal short of the working length that the determined specific pressure needs to be exceeded in order for additional advancement to occur while using 1 mm increments of insertions, that depth of penetration denotes the coronal zone. The .25 tip is used to detect a constriction and the .06 taper has the rigidity that will resist a curvature. The most reliable files for following this procedure include the K-3, Quantec and the RaCe files. This second technique for determining the **coronal zone** requires a learning curve and should be employed only after sufficient experience.

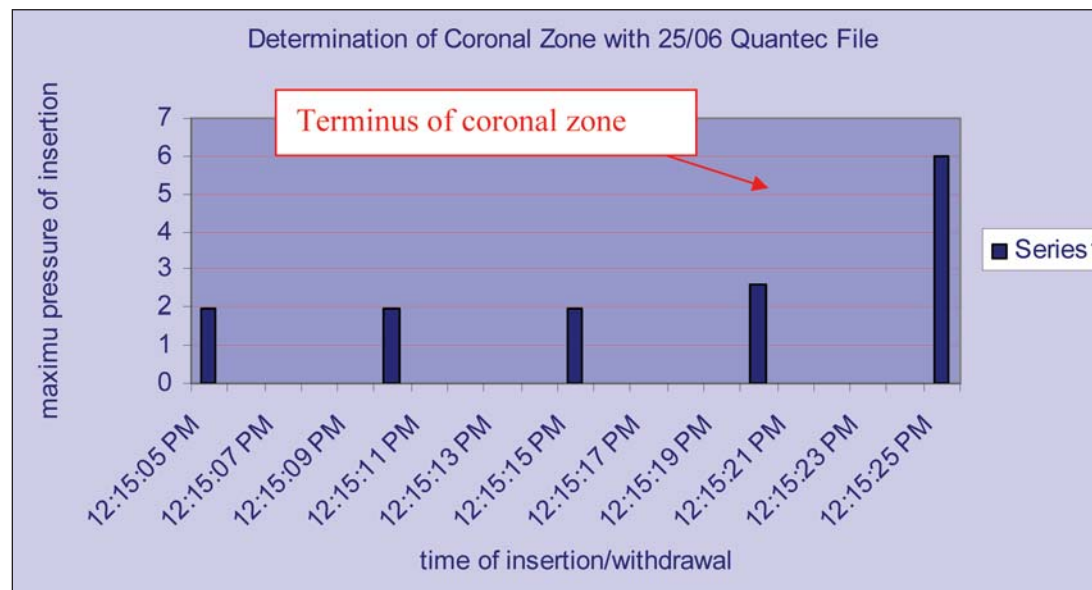


Table 122 A Quantec 25/06 file was inserted and withdrawn at a rate of ½ mm/s. It was inserted 2 mm and withdrawn 1 mm with each cycle. The peak pressure in pounds per square inch was recorded with each cycle. The pressure for the 5th insertion (5th mm depth of insertion after engagement) was substantially higher than any previous insertion. This level indicated the terminus of the coronal zone.

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Fig. 123

The red arrow indicates the type of anatomical restriction or curvature represented in the chart above that would require an increase in pressure to advance to a greater depth in the canal. Assuming that this is at the 5mm depth after the file became engaged as in the chart above, this level would represent the terminus of the coronal zone. Stress on the files is minimized of the apical zone beyond the curvature is prepared with a technique that considers the file diameter as it transgresses the curvature.

The Zone Technique for canal preparation

The zone technique was designed with two objectives for minimizing file stress for any type of NiTi rotary file: One, the canal diameter should be large enough coronal to a curvature to prevent any engagement in that portion of the canal when any file is being used apical to the curvature. Two, the file diameter is not too large to rotate safely in a curvature.

The first step is to determine if there is a curvature of any significance and how far the curvature is from the apex. Withdrawing the

file used to establish the working length, and passively re-inserting will indicate a curvature if it meets any resistance short of the working length since the canal is now larger than the file. The canal portion short of the resistance defines the **coronal zone** and the portion beyond the resistance defines the **apical zone** (Fig. 124). The length of the canal to the curvature, the coronal zone, is measured and recorded with the same importance as determining the working length. The working length minus the coronal zone length provides the distance the curvature is from the apex, the apical zone length.

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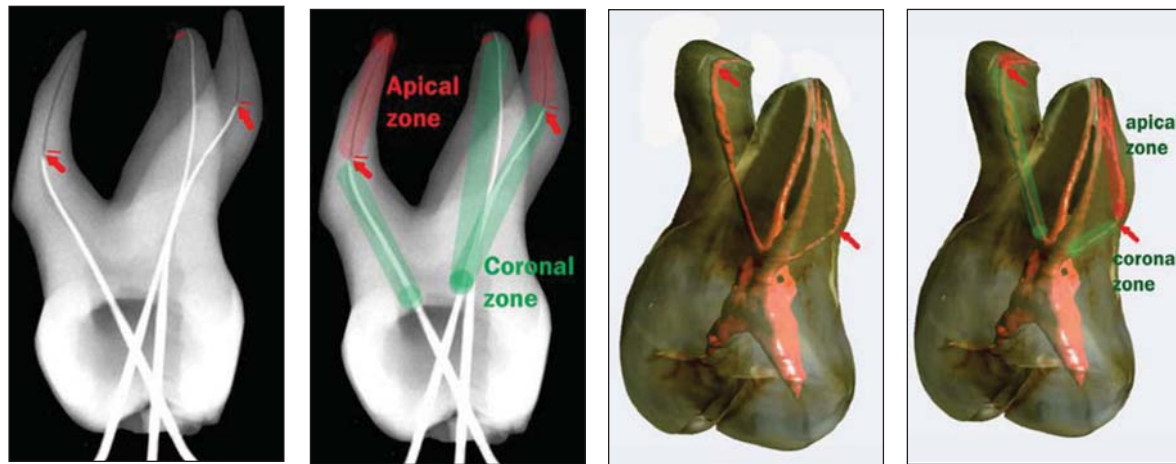


Fig. 124 The points of resistance files encounter, indicated by the arrows, when passively being inserted into canals having a larger diameter, divides the canals into coronal and apical zones. The zones require different preparation approaches.

The second step is to determine the distance each of the files having different sizes and tapers can safely be advanced around the curvatures and which size file will need to be used in the coronal zone to prevent any subsequent file from binding in the apical zone. By using the parameters suggested above for diameter limitations (*.60mm for a .02 taper, .55mm for .04 taper, .50mm for .06 taper, and .35mm for a .08 taper*), we can calculate if the diameter of a selected file would exceed our limitations. That determination can be calculated by using the following formula:

Diameter limitation* (-) tip size (÷) taper (=) the length the file can be projected around a moderate curvature.

**no more than .60mm for a .02 taper, .55mm for .04 taper, .50mm for .06 taper, and .35mm for a .08 taper*

Example 1: If we select a size .25/.04 taper file to negotiate the canal illustrated in Fig. 125, the diameter limitation suggested in the parameter is .55 mm. The .55 mm diameter limitation minus the tip size, .25 mm, is .30. The difference, .30, is divided by .04, the

taper, which equals 7. The number of millimeters a .25/.04 file can be advanced beyond a moderate curvature is 7 mm and therefore, can be used to the working length in this situation. A size .50/.04 or larger would be required to enlarge the coronal zone to prevent any engagement in that portion of the canal while using a .25/.04 file to the working length.

Example 2: If we select a size .25/.06 taper file to negotiate the canal illustrated in Fig. 125, the diameter limitation suggested in the parameter for a .06 taper is .50mm. The diameter limitation, .50mm, minus the tip size, .25mm, is .25. The difference, .25 divided by .06, the taper, is 4 and is the number of millimeters a .25/.06 file can be advanced beyond a moderate curvature or into the apical zone and, therefore, should be advanced no closer than 2mm from the working length in this situation. A size .50/.06 or larger would be required to enlarge the coronal zone to prevent any engagement in that portion of the canal while using a .25/.06 file to the working length.

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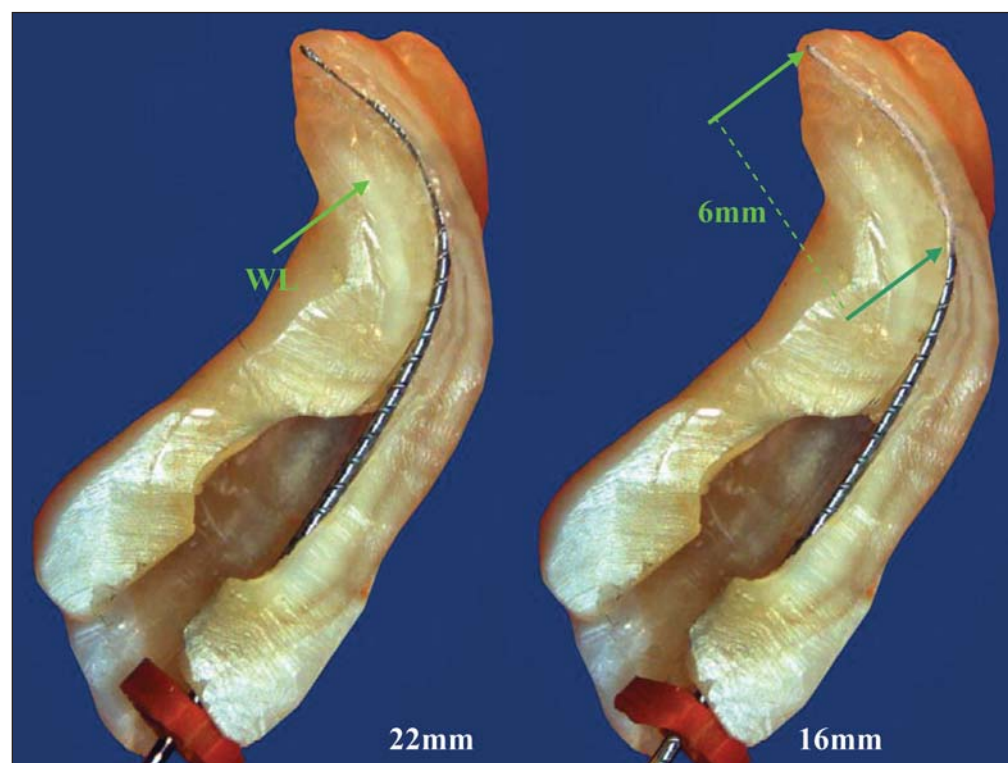


Fig. 125 The recorded length at which the smaller file encounters resistance in a larger canal can be subtracted from the working length to obtain the distance the curvature is from the working length.

Once this procedure is followed, the terminus of the canal can easily be enlarged by using .02 tapered files. For more severe curvatures, the file sizes need to be reduced accordingly. Although the zone technique does require some mental exercise, hopefully within the capacity of any dentist doing root canals, its advantages can result in major reductions in preparation time and file stress.

53. How do I prepare the coronal zone?

The coronal zone presents no particular problems as long as it can be defined and its terminus is not violated. Essentially, the coronal zone is a straight canal and the considerations for preventing file breakage can easily be applied. The selection of the first file for preparing

the coronal zone should meet two objectives. The file tip should be small enough to negotiate the entire coronal zone yet rigid enough to tactilely detect any point of curvature or a restriction that requires an increase in applied pressure for apical advancement. The final preparation of the coronal zone should be large enough to avoid or minimize engagement of any subsequent file and provide adequate access for obturation. A frequent mistake is to use tip diameters at the terminus of the coronal zone that are smaller at that point than the diameters for files used in the apical zone. For instance, if a 25/.08 file is carried to the terminus of the coronal zone and a 25/.02 file is carried 5 mm apical to that point, the 25/.02 will be engaged in the coronal zone, since its diameter will be .35mm at the terminus of the coronal zone.

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When encountering a canal anatomy that cannot be instrumented with conventional techniques while following the parameters listed above, closely following an exercise for designing a technique modification that will

conform is an excellent mechanism for learning efficiency and avoidance of file failure. Examples for technique procedures that conform to the instrumentation rationale presented thus far are as follows:



Fig. 126 The tooth illustrated has been sectioned to expose the mesio-buccal canal. The curvature begins 6 mm from the apical foramen and its radius is slightly less than 8 mm. Adjacent to the canal are the canal diameters prior to instrumentation from the foramen to the canal orifice.

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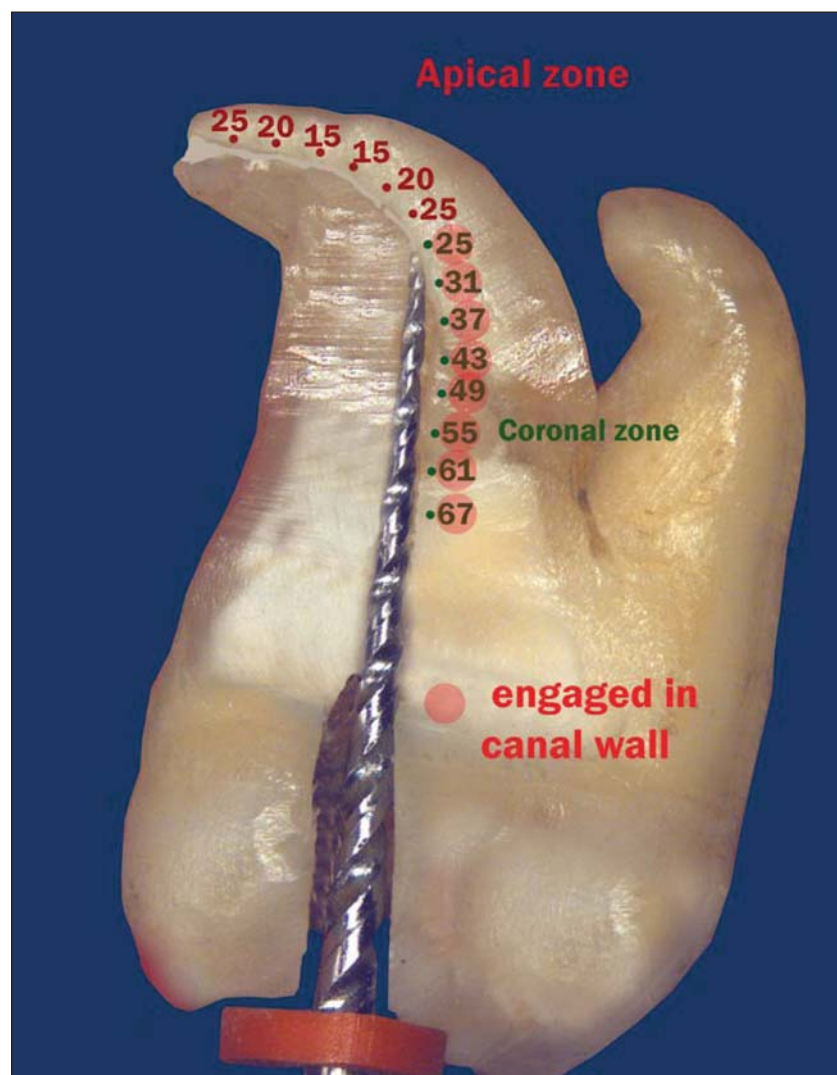
Step 1. Determine the terminus of the coronal zone.

Fig. 127 A 25/06 Quantec SC is taken to the terminus of the coronal zone (6 mm from the working length). The file, rotating at 350 rpm, should be advanced into the canal in 1 mm increments with insertion-withdraw movements. Each insertion should not require any more pressure than was required for its first insertion once engaged. When a position is reached in the canal that requires more pressure for advancement, that position is a good indication of the terminus of the coronal zone. In order to ascertain the position of the terminus, a file smaller than the canal can be advanced until resistance is met. For instance, if a 15/02 is carried to the working length and withdrawn and reinserted, and resistance is met at some point, then that point denotes the terminus of the coronal zone. The two positions should be the same. The numbers in pink denote the levels of file engagement.

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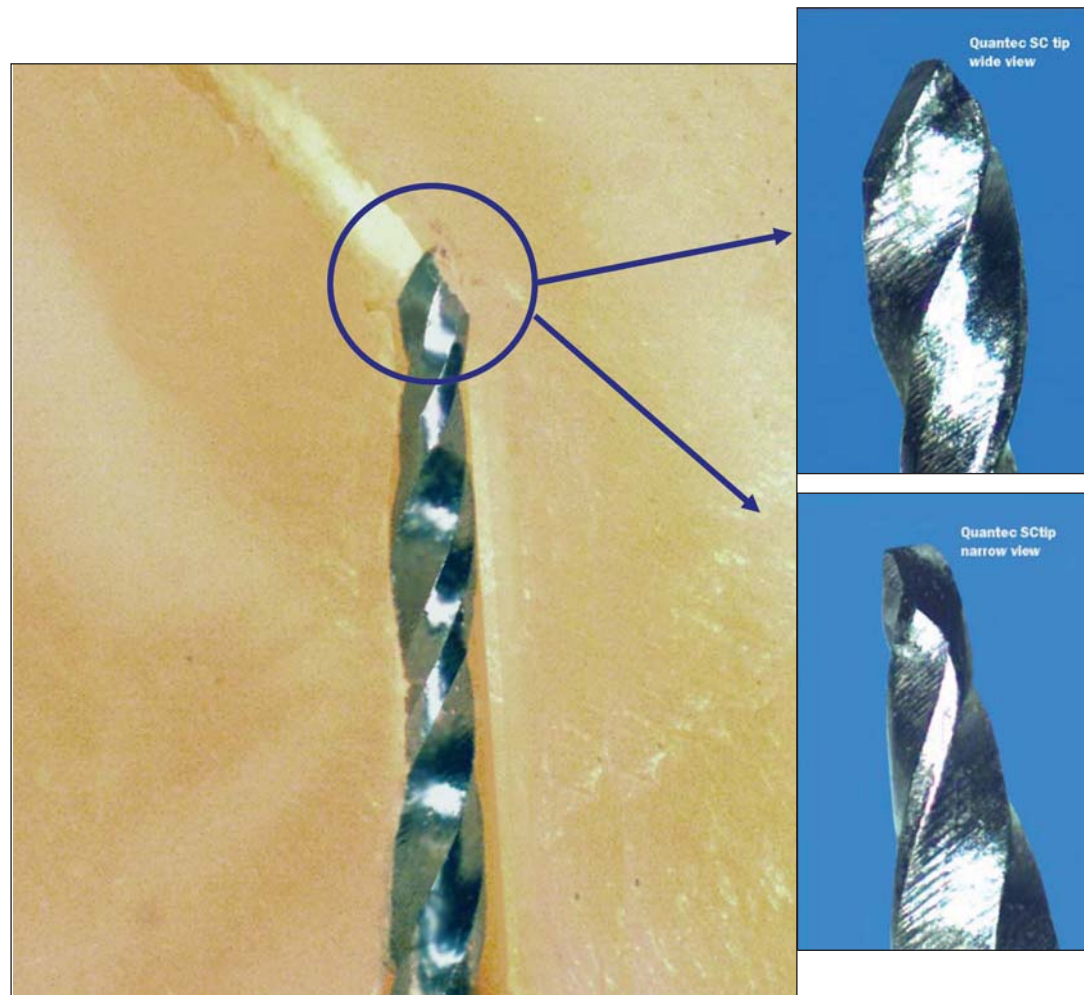


Fig. 128 Defining the coronal zone. The area in the circle illustrates where the file meets the increased resistance of a curvature and defines the terminus of the coronal zone. Images A and B illustrate different views of the .25 SC tip; one rotated 90 degrees from the other. The Quantec SC 25/06 was selected as the first file to negotiate and to define the coronal zone for 3 reasons, (1) The two fluted spade-shaped Quantec SC tip will enter and enlarge a canal orifice as small as .10 mm. as illustrated in the A and B images. (2) The Quantec SC .06 taper file had the most favorable safety ratio of any of the files tested with its dimensions. (3) The .06 taper is small enough to advance into the canal without requiring excessive pressure and it has sufficient rigidity to tactilely detect restrictive curvatures.

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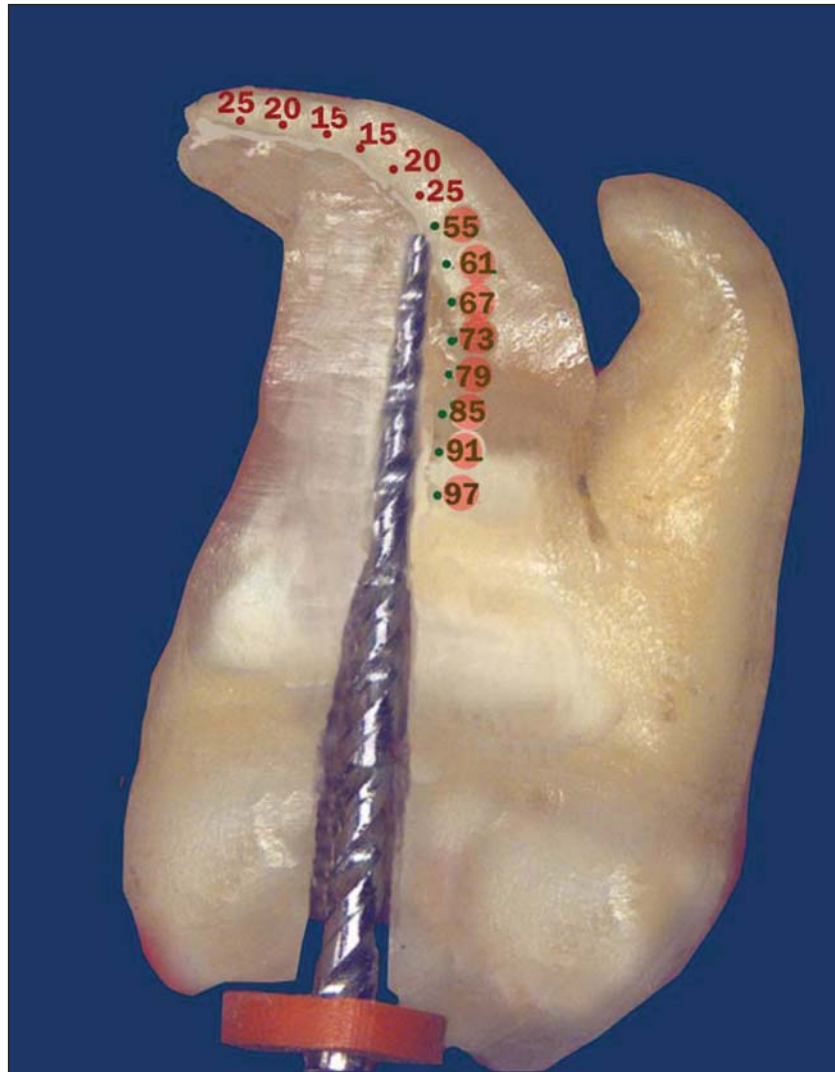
2. Determine the diameter needed in the final enlargement at the terminus of the coronal zone.

Fig. 129 55/06 K-3. Having the same taper as the 25/06 file, it is helpful to circumferentially file the canal during its advancement. This file was selected because of its resistance to distortion and its high cutting efficiency. By cautiously removing this file to a position short of its maximum insertion, the speed of rotation can be increased to 1,000 to 1,200 rpm to selectively reposition the canal orifice and taper of the coronal zone (to reduce the amount of engagement during its progress) to sufficiently enlarge in order that subsequent files will not become engaged, and to enlarge the canal access to conform to dimensions needed for ease of obturation. The Quantec/K-3 design is particularly effective for this type canal enlargement. Care must be taken not to engage the tip of the instrument by carrying it to a greater depth.

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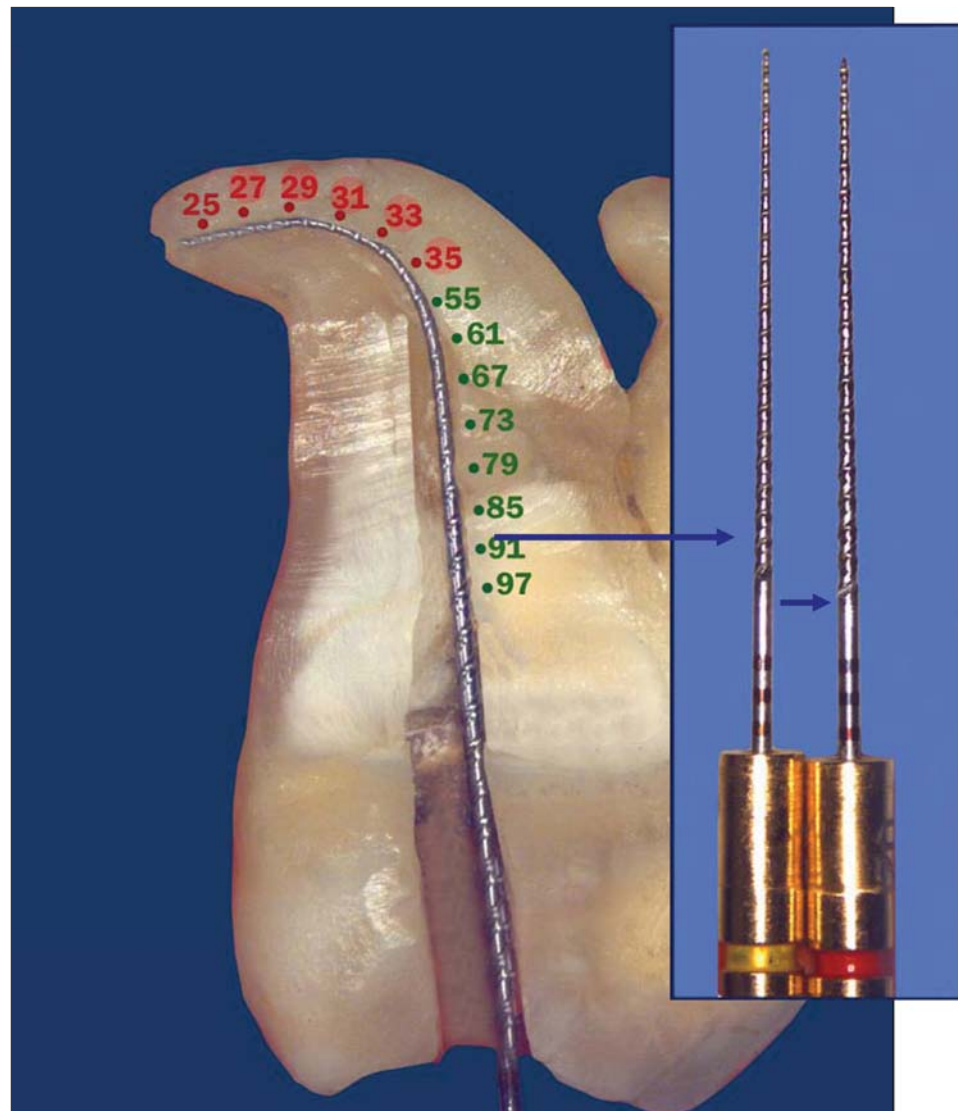
Step 3. Enlarge the apical zone to a size 25/.02.

Fig 130 Advance the 15/.02 Quantec SC to terminus of apical zone (working length), followed with a 20/.02 and a 25/.02 Quantec LX to working length. The Quantec .02's were selected because they have the highest safety ratio for .02 files and the greatest cutting efficiency during penetration. The SC tip was selected for the 15/.02 file because of the uncertainty of the canal diameter and the reduced risks of canal transportation with its flexibility. Since the largest diameter at the terminus of the coronal zone was .55, the maximum diameters for the .02 files at the working length are smaller and the files are only engaged for 6mm.

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Step 4. Enlarge the apical zone to the desired dimensions permissible.

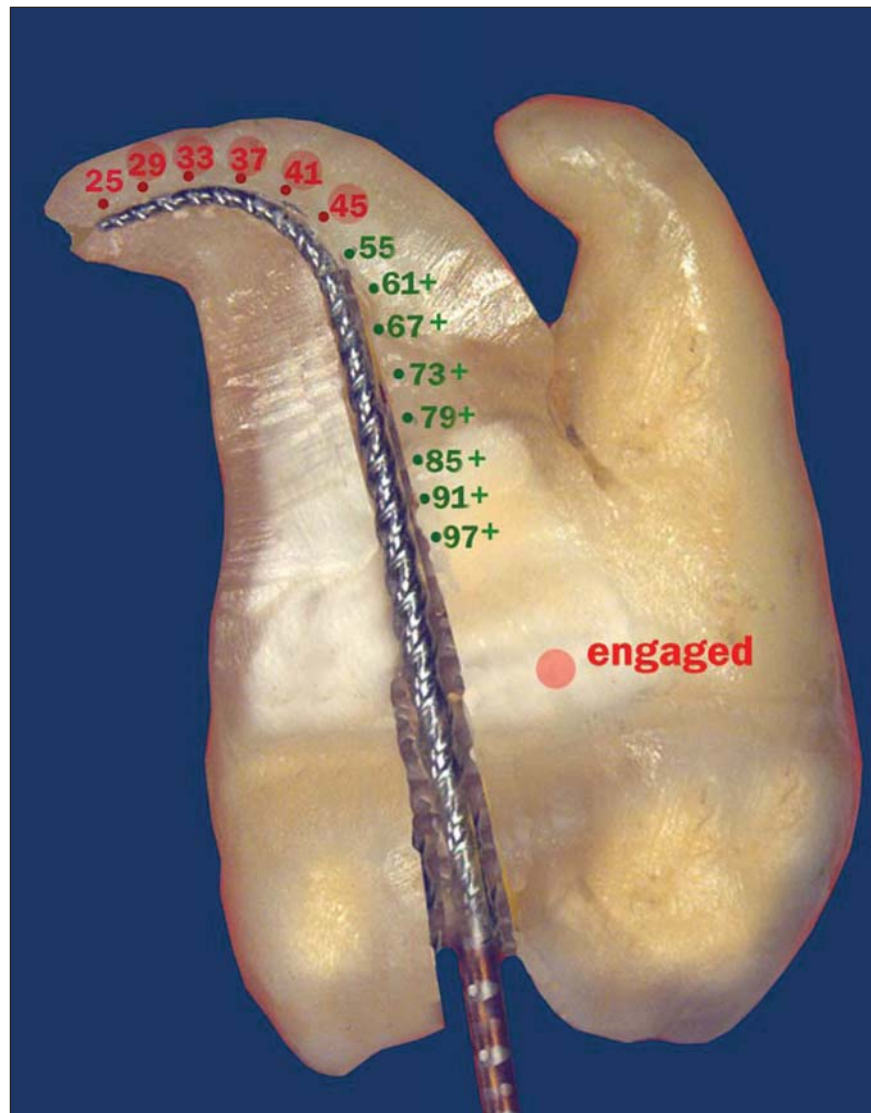


Fig. 131 25/.04 K-3 taken to terminus of apical zone. Following this procedure the file tip remains passive until it reaches the working length and is only engaged for 6 mm. The largest diameter of this file to be engaged is .45. The K-3 file was selected because it demonstrated the highest efficiency of any of the files tested.

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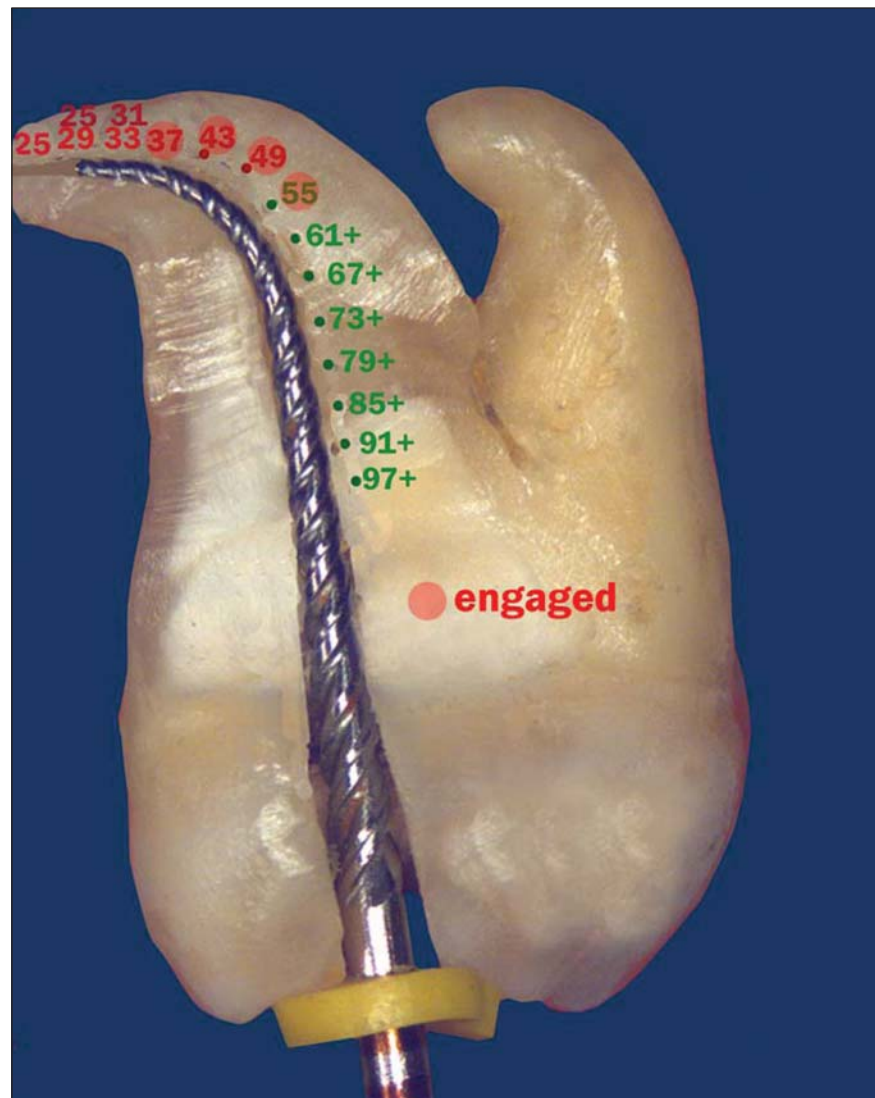


Fig. 132 25/.06 K-3 taken 1mm short of working length. Any additional taper or apical diameter should be provided by using .02 or .04 tapered files with a step-back technique in the apical zone. The enlargement of the coronal zone can be determined by the requirements of the operator. Each file in the sequence used conforms to the parameters discussed above. The K-3 was selected for its high efficiency.

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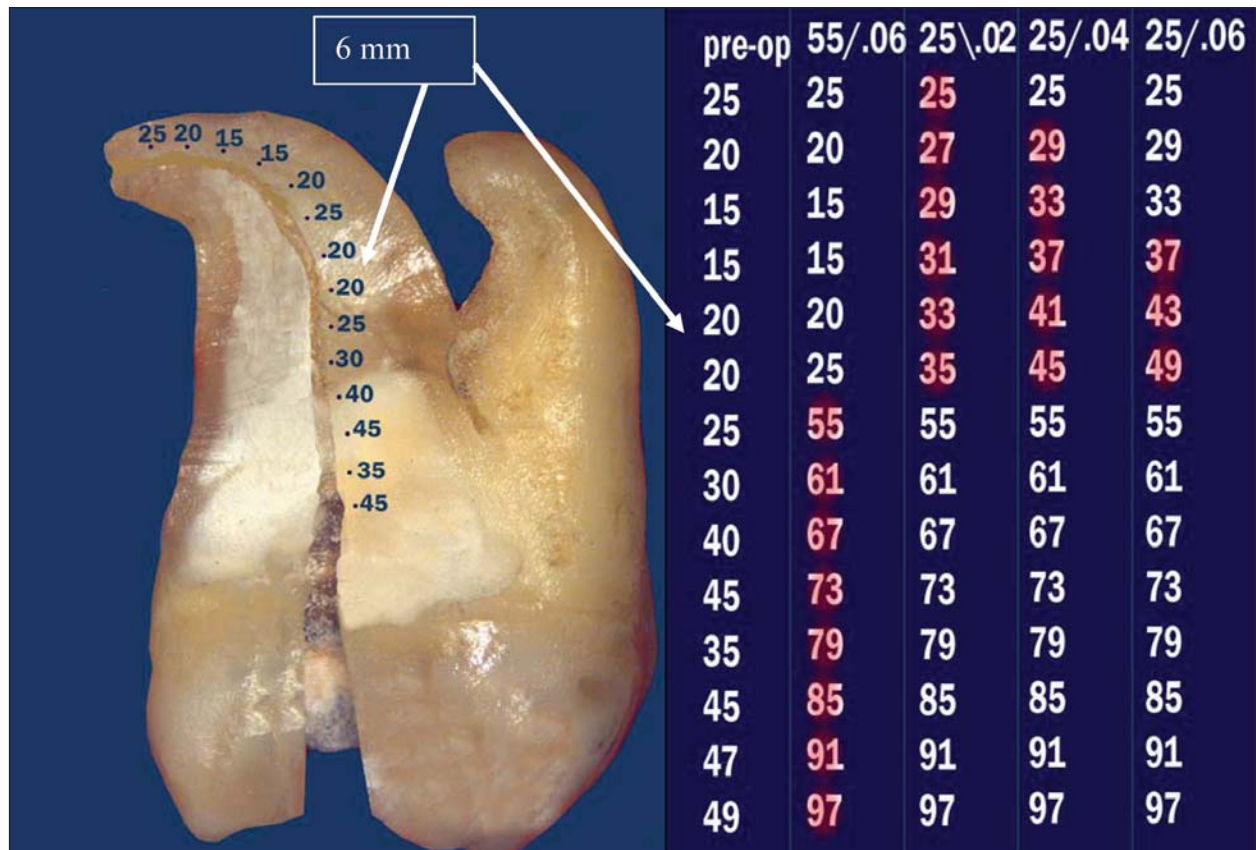


Fig. 133 This illustration is another means of representing the case above indicating the instruments used and the depths of advancement. Using this type representation enables one to determine if all the parameters are followed. Note that the K-3 25/.06 required advancing 1 mm short of the working length in order to conform to the parameters. Depending on the tip design, the use of a size 25/1.0 or larger orifice opener could facilitate enlargement with less engagement if used before the 55/.06 file was used in the coronal zone.

As discussed above, the K-3 files and Quantec files were used because results of the particular tests employed in our evaluations indicated either file provided a better safety ratio or greater preparation efficiency. Most other file series have the same file sizes available and can be used in the same manner to conform to the prescribed parameters. The Protaper Series is an exception that has files with unique accelerating and decelerating tapers. Although the coronal zone can easily be prepared with the Protaper Series, the apical zone cannot effectively be prepared while performing within the parameters, par-

ticularly without engaging more than 6 mm of working surface or without using large diameters in the curvature.

The above example was used to illustrate all of the limitations the parameters place on canals that have curvatures that extend six or more millimeters from the working length. Techniques for preparing mid-root and coronal curvatures require more step-back approaches with .04 and .02 tapers to conform to the parameters.

If the parameter of taper and diameter limitations for a canal having a 45-degree curvature and a 8 mm radius is used as a

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reference, the limitations of file dimensions in canals having different curvatures can be extrapolated mathematically. Two factors, the working length and the curvature radius, need to be considered in determining the file taper and diameter that can be used in the anatomy illustrated above while adhering to the recommended parameters. For instance, if we want to know how far we can advance a 25/.06 file beyond the point of curvature the parameters state the diameter should not exceed a .50 mm diameter which is reached when the file extends only 4 mm beyond the point of curvature. However, if the radius of curvature is 16 mm or two times the amount stated in the parameters, the diameter used can be larger. The relationship is based on the square of the file diameter. The square root of two times the .50 mm diameter squared equals a size .70 mm diameter which means a 25/.06 file can be advanced to the working length without undue stress on the file. That determination assumes the other parameters are considered. Although the first impression of this process may seem complicated, little exercise is required to master this approach. The benefit is efficiency and the reduction of the threat of failure. *If the clinician insists on following a routine technique sequence because consistency weighs heavily in their practice efficiency, then the sequence described in Fig. 133 encompasses all of*

*our considerations for minimizing instrument stress while providing an efficient routine for **routine canals**. That technique sequence is as follows:*

1. 25/.06 to curvature
2. 55/.06 to curvature
3. 25/.02 to working length
4. 25/.04 to working length
5. 25/.06 1 mm short of working length

The exceptions to "routine" of course, is any canal having an apical zone greater than 6 mm, a curvature less than 45 degrees and a radius less than 8 mm.

54. Can files be designed so you do not have to calculate how to avoid excessive stress?

Excessive stress on files of current designs can be avoided. This can be done if the cause of stress is understood and calculations are made as to where and how files can be used. Files can and are being designed that minimize mistakes in calculations and judgment. Since the two most frequent causes of file breakage are the result of using files having diameters too large for the degree of canal curvatures and engaging too much of the file's working surface, designs can be incorporated to minimize these events. Addressing design changes for reducing potential stress is the purpose of the next section.

Section IV. Mastering Future Developments

The purpose of the previous sections was to examine the factors that cause file designs and techniques to be attributes or liabilities, successes or failures, and to determine if modifying techniques and the selection of existing instruments could improve the results of instrumentation. As one follows the sequence of thoughts during this process, the question that comes to mind is: "What constitutes a more ideal file design and is there an ideal technique?"

The ultimate purpose of this book is to help provide the means to advance the development of new root canal preparation modalities. Since the clinician is the only one who has first-hand knowledge of what problems exists, he or she needs the framework of understanding to personally become involved in the development of instruments or to guide manufacturers toward progress. The future of endodontic instrumentation cannot afford to rely on intuitive ideas that might or might not result in advancement. Just as instrumentation expertise relies on the understanding of rudimentary concepts of physics, so do advancements in root canal instrument developments. At the very least, clinicians need to thoroughly understand the instruments and the consequences of how they are used.

55. What improvements are being implemented to facilitate instrumentation?

Presently, we see improvements occurring in three areas:

(1) One improvement discussed extensively in this book, is the approach undertaken in the selection and use of the most appropriate instruments for particular tasks that are currently available. Dentists are beginning to question routine cookbook type procedures and attempting to look for answers.

(2) Manufacturers have begun to incorporate design changes to minimize the stress of blade engagement.

(3) And, to a limited extent, we are beginning to see new materials available for enhancing the properties of files and new

manufacturing processes for fabricating designs.

Regrettably, the progress for innovative design changes is hindered by the aggressive defense of questionable patented intellectual property and marketing resistance for new product introductions. Nevertheless, new file designs incorporating the potential improvements discussed earlier have been found to have significant advantages for the reduction of the stresses of instrumentation and are finally becoming available to the profession.

56. What instrument designs reduce the use of excessive stress?

Research is the most useful tool for gaining insight into realms beyond the reach of ordinary perception and experience. In examining

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the results of current research, trends become apparent for formulating instrumentation designs and techniques. The primary consideration is to set parameters for preventing file failure and eliminating unnecessary or counterproductive procedures. By observing the situations that usually have a high incidence of file failure, we can then test designs and procedures to effectively avoid those situations. Once results are examined, then modifications can be incorporated to achieve the most optimum means of instrumentation. Comparing the features of new instruments as they are introduced with stress reducing designs, can be an indication of the merits of change. Testing indicates instrumentation should encompass as many of the following considerations as practical for safe and effective rotary instrumentation:

1. Incorporate positive cutting angles to enhance the efficiency of canal enlargement.
2. Minimize any land width or use regressive lands to reduce abrasion on the canal surface.
3. Provide an asymmetrical cross-section to the file to aid in maintaining the central axis of the canal.
4. Reduce file engagement and screwing in forces by reducing, eliminating or interrupting the number of flute spirals to the smallest number necessary while preventing excessive torque that results from the accumulation of debris.
5. Reduce the distance between the minimum diameter and the maximum diameter in order that the torque required for rotating a fully engaged working surface is not greater than that needed to exceed the ultimate strength of any part of the file.
6. Reduce the difference between the file's minimum diameter and maximum diameter so the torque required for rotating the larger diameter is not greater than the torque which would cause the smaller diameter to be distorted beyond its plastic limit.
7. Provide a zero taper or nearly parallel portion of the file so the apical portion of the canal can be enlarged without the need for large diameters of the file to rotate in canal curvatures that cause undue file stress and canal transportation.
8. Adjust the shaft diameter so potential breakage would occur near the file handle in order to make it more accessible for removal.
9. Utilize a technique to complete the file function before the file flutes fill with debris.
10. Interrupt the continuity of blade engagement with intersecting grooves or by providing an undulating core axis or file profile to reduce total blade engagement.
11. Reduce blade engagement and land abrasion by utilizing different flute and outside tapers in the same instrument.
12. Reduce the number of flutes having similar helix angles. Dissimilar helix angles reduce the screwing-in forces. Flutes with no helix angles eliminate screwing-in forces.
13. Provide a file surface that exhibits greater lubricity to reduce frictional resistance and facilitate debris removal.
14. Provide a file surface that has reduced micro-grooves that cause stress concentration points for potential crack propagation.
15. Provide a design that avoids abrupt changes in design configurations in order to reduce stress concentration points.

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16. Provide blades that are appendages or projections from the file shaft instead of blades that result from grinding a groove into the shaft.
17. Provide channels along the long axis of the file to facilitate by-passing the file and its removal if breakage should occur.

What stress reducing design changes have been incorporated as improvements on initial designs or can readily be incorporated in files as attempts for improvement?

The purpose of the following illustrations, of how files have or might be modified to enhance their function and safety even though they may never reach production, is to stimulate greater operator interest in file and technique improvement. The greatest untapped resource for file and technique design very possibly is the dentist himself or herself. File modifications that have incorporated stress reduction features include the Hero file change to the Apical file, the Light Speed file change to LSX file, and the Power-R file to the Liberator.

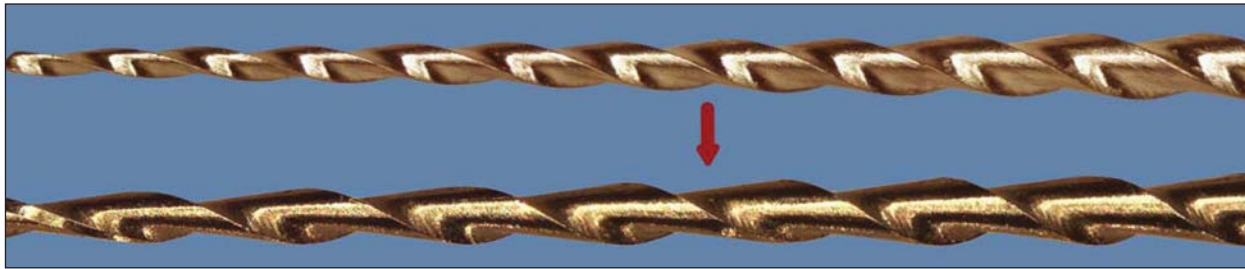


Fig. 134 Micro-Mega increased the efficiency of the three-fluted H-type file design by incorporating the stress reducing features of reducing the number spirals to reduce blade engagement and by increasing flute depth for more effective debris removal. Also the cutting edges are not as heavily polished and are sharper.

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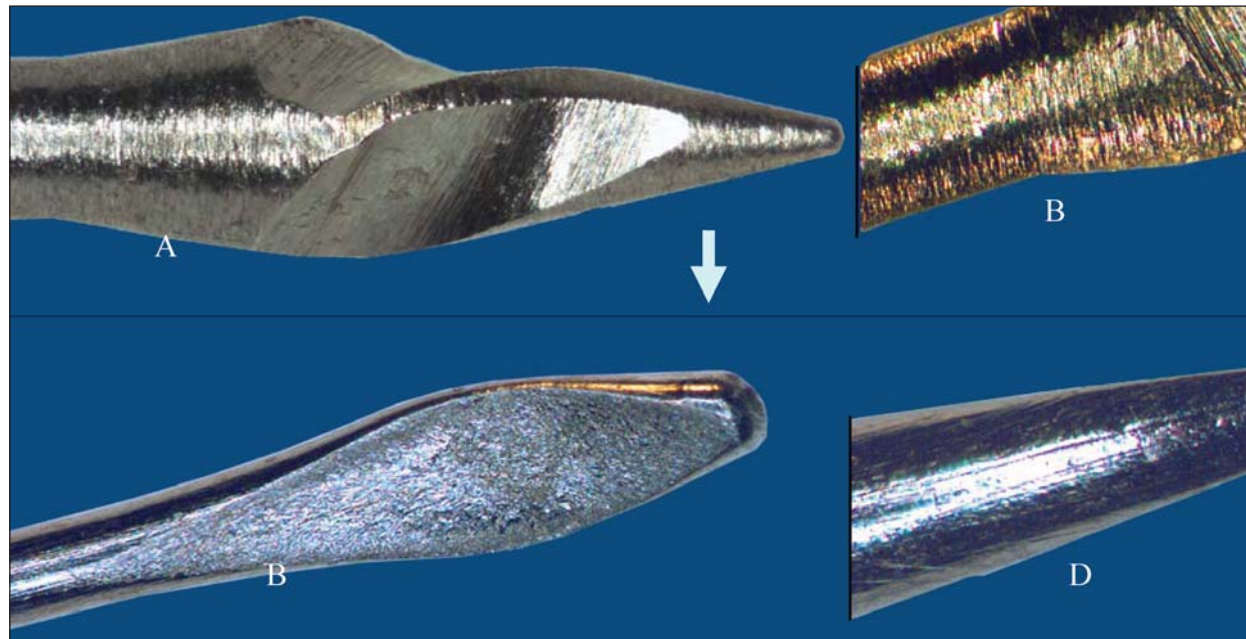


Fig. 135 The Light Speed file (A) has been replaced with the LSX (B). The new design is stamped on extruded wire (D) rather than being ground, which eliminates the surface micro-grooves (B) that contribute to fatigue. The cutting edge is more positive, engagement is reduced by eliminating spirals, and bypassing the file is facilitated. The new Light Speed design, the LSX, is formed by compressing an extruded NiTi wire by striking its surface to form two flat flutes adjacent to its tip. The advantage of this design is its increased flexibility and the elimination of the circumferential faults that were more likely to cause fatigue and torsion failure. Its disadvantage is its reduced debris removal ability as a result of the elimination of spirals.

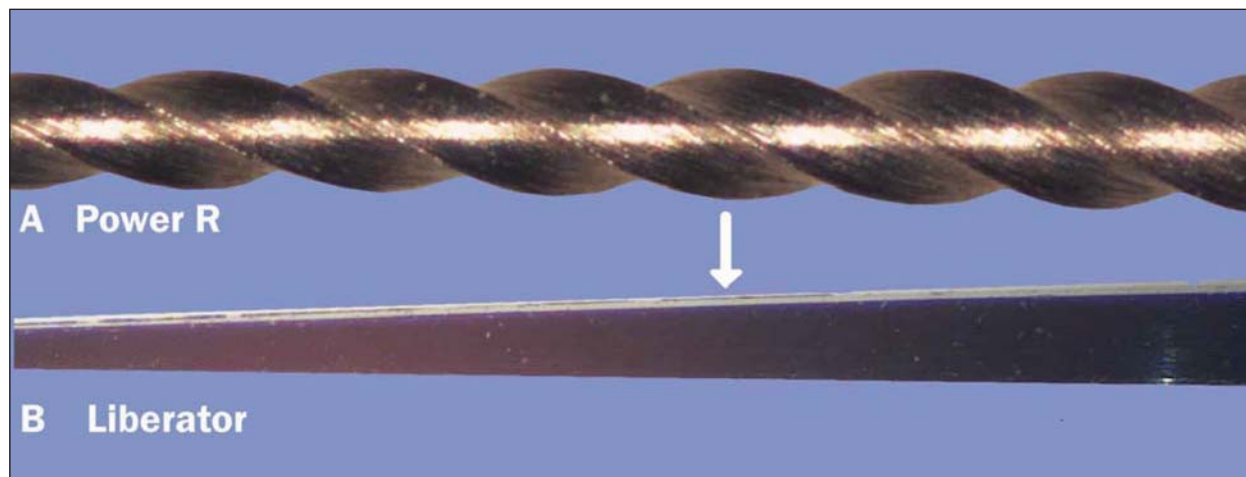


Fig. 136 The Power R file (A) has been superseded with the Liberator file (B). Engagement has been reduced and screwing-in forces have been eliminated by incorporating no spirals.

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If one wanted to take the Liberator file as an example exercise for incorporating more potential stress reducing features, the first step might include increasing efficiency and limiting engagement by:

(1.) Providing more positive cutting angles.

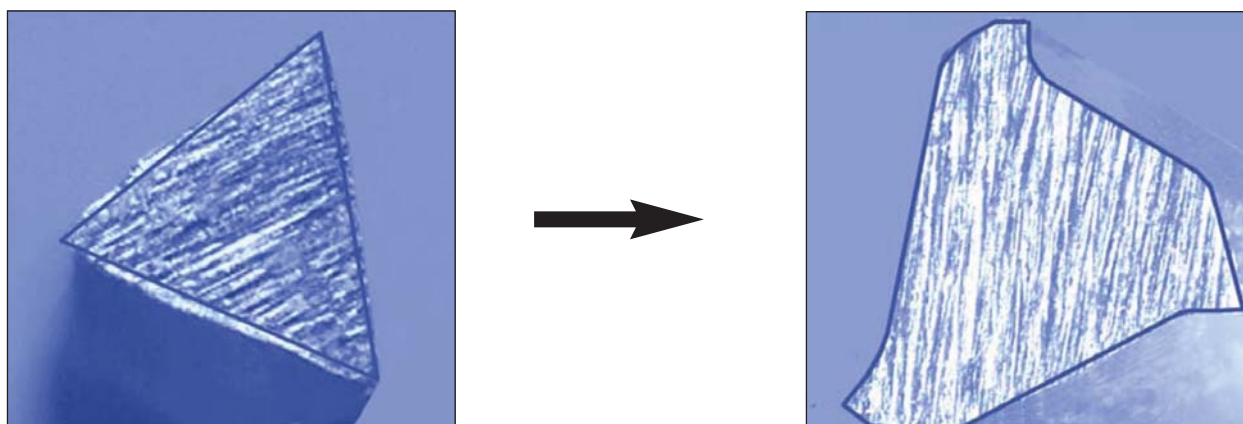


Fig. 137

(2.) Providing “notches” that can be ground across the corners of the non-spiraled file or a round tapered wire to result in less engagement, more efficient cutting, greater flexibility, and enhanced debris removal. The notches can be cut at different angles to reduce screw-in forces and to break up the chips for easier removal.

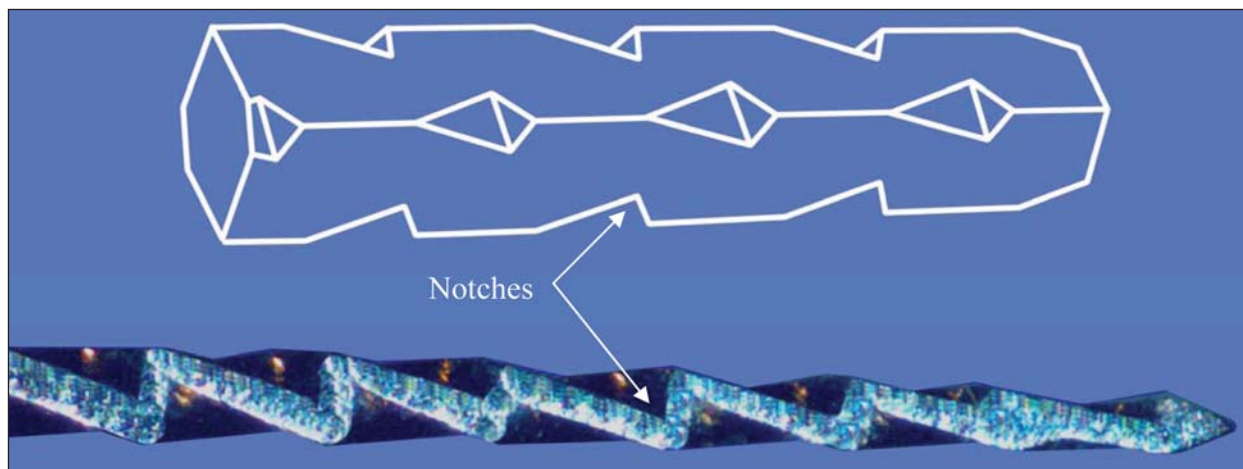


Fig. 138 File with notches that transverse a corner (McSpadden prototype)

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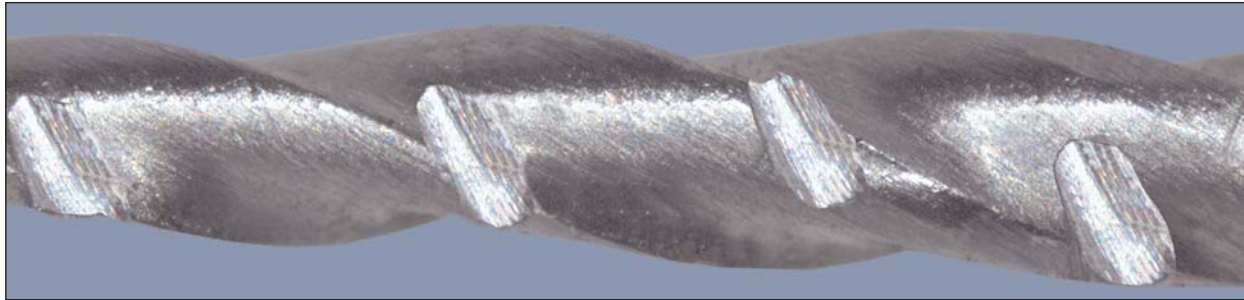


Fig. 139 File with notches that transverse a spiral (McSpadden prototype)

56. How can the more complex designs of files be improved for stress reduction?

Most would agree that the K-3 file design is the most complex file design available at the time of this writing. The complexity is the result of incorporating positive cutting angles, lands, and asymmetry into its design. Consequentially, the K-3 design is an excellent example to illustrate how applying stress reduction design changes to prototypes can enhance its performance and simplify its use. Each design feature listed above will be considered and applied individually to the K-

3 design if appropriate and the design evolution for potential introduction will be illustrated as follows:

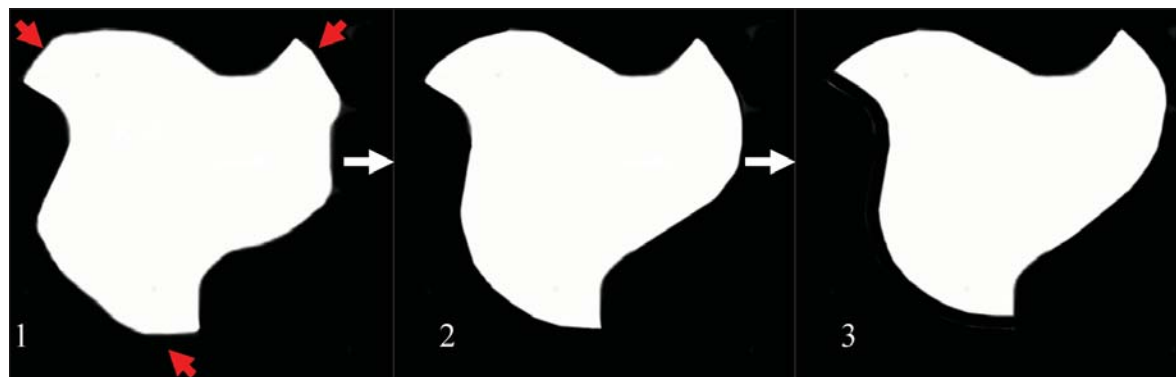


Fig. 140 The cross-section design. While retaining the positive cutting angles of the K-3, in image 1, the design of the cross-section is enhanced by first replacing the lands indicated with the red arrows with the recessive lands in image 2. Although lands are especially effective in supporting the edge of the cutting angle and reducing canal transportation, recessive lands significantly reduce the lands' torsion of abrasion. In order to compensate for any potential increased propensity for transportation, the asymmetry of the design is augmented in image 3. The resulting design also provides an undulating core and greater flexibility.

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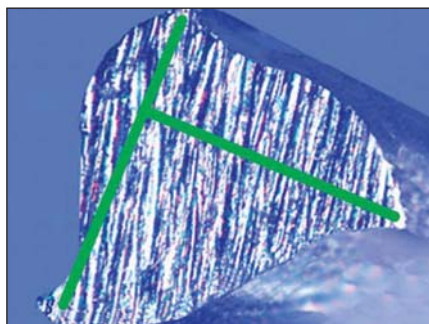


Fig. 141 The asymmetrical 3-fluted cross-section design has unequally spaced flutes to reduce the tendency for canal transportation and recessive surfaces instead of lands to reduce frictional abrasion while engaging the wall of the canal

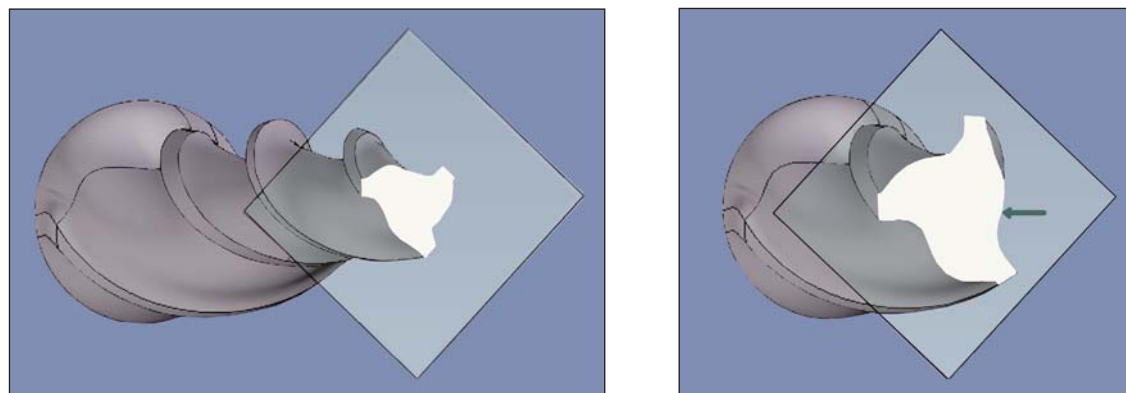


Fig. 142 Asymmetrical fluting. Incorporating different flute tapers along the shaft of a file can offer numerous advantages including a means for increasing its efficiency and flexibility at the handle end while maintaining strength at its tip end (i.e. the file illustrated above has 2 flutes that have a .06 taper and the third flute has a .04 taper).

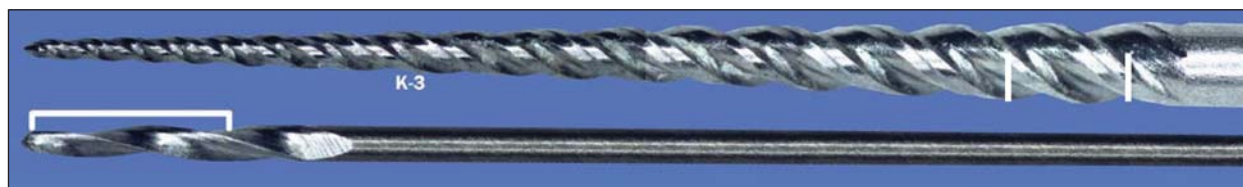


Fig. 143 The longitudinal design. Once the cross-section design changes are redesigned, several longitudinal changes can be incorporated simultaneously. Blade spirals, per unit length, can be reduced. The distance between the maximum and minimum diameters can be reduced, indicated by the white lines. The difference between the maximum and minimum diameters can be reduced. A zero taper can be provided on the file portion not to be engaged in order to provide greater flexibility.

The segmented approach for canal enlargement. Once the file design changes for reducing stress are incorporated, design dimensions can be calculated for a more efficient and stress reducing technique. Rather than dividing the canal into zones, for reducing the stresses of instrumentation, as described in the previous section, the same result can be

simplified by dividing the working surface of a file into sections, corresponding to the section of the canal to be prepared. As was illustrated in the previous section, the most efficient and least stressful use of files requires calculating what part of the file will be engaged, and the regimented steps of crown down and step back techniques may not provide the best means for reducing the chance for

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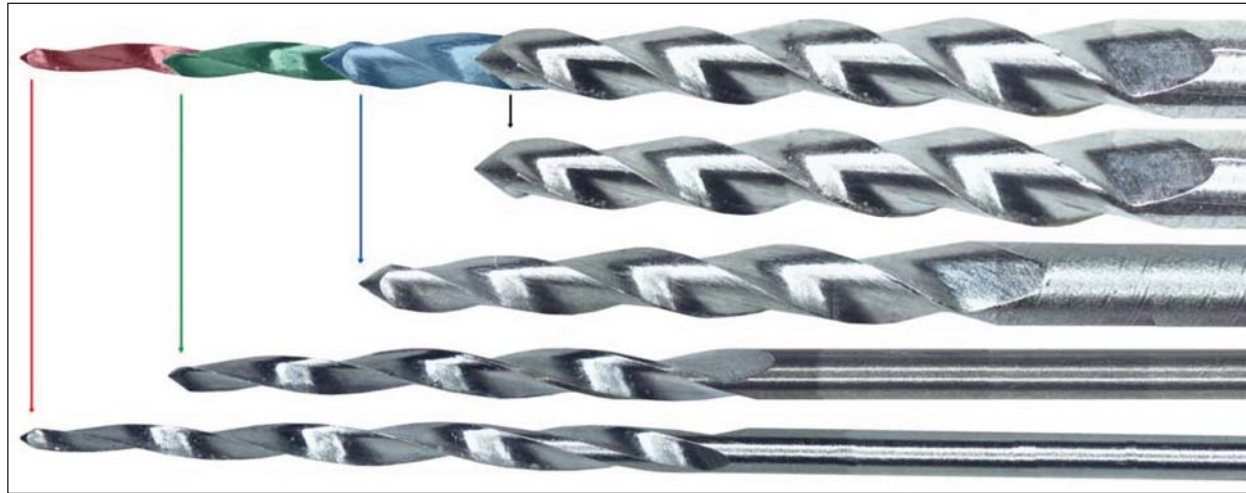


Fig. 144 The positions of stops are measured from the handle end rather than from the tip.

failure. **The Segmented File** concept is the first file series to limit the stress the file encounters, by limiting its blade engagement, relative to the demands of the canal anatomy. Rather than arriving at a final canal shape by using a series of instruments that gradually changes the shape of the total canal, by using a series of different file tapers and sizes, each segment of the canal's length is essentially prepared to its final shape with one instrument. The file design and dimensions can be specifically fabricated for the length and diameter of each particular canal section and the total canal shape is made up of a composite of segments. For instance, by reducing the length of the file's working surface and reducing the flute spirals, the engagement of the more vulnerable smaller file diameters is limited. As the size of each file segment becomes smaller in diameter, its tapered working surface is reduced and its overall length is increased.

Segmented Series. *Appropriate to its diameter, the tapered working surface of each file is limited to reduce the stress of engagement. As the size of each file in the series becomes larger in diameter, the length of*

the file becomes shorter by the length of the previous file's tapered working surface. The example segmented series above illustrates how a 25/.06 conventional file can be divided into four .06 tapered segments in order to limit the potential stresses on the file. The most coronal portion of the file does not have a segment since an orifice opener would incorporate that portion of the preparation. The maximum and minimum diameters of each file slightly overlap those of its adjacent segment, but the file does not have to be used in any sequence.

The files can be used in any sequence since its total engagement will be limited to the length of its working surface.

The canal can be prepared using a crown-down, step-back, or any sequence to result in a continuous taper (with each file assuming the preparation where the previous file ended it or at a position appropriate to that section of the canal). The final preparation results as a composite of segment preparations that equals the desired final shape of the canal.

By using this approach, only a minimum

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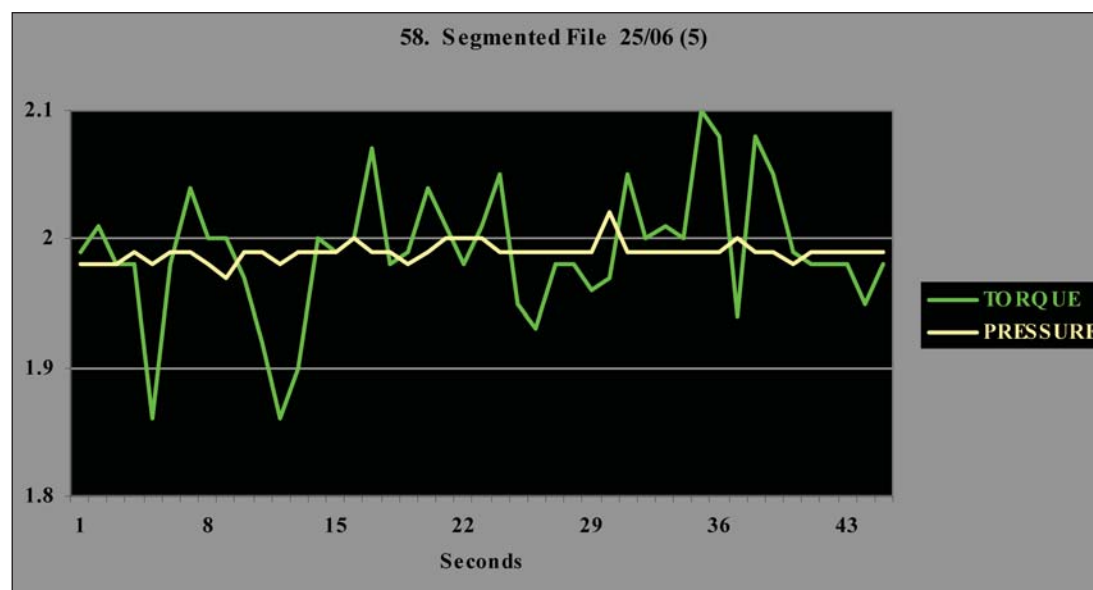


Table 145 The above graph charts the torque that was generated, during which a 25/06 Segmented File with a maximum diameter of .45 mm was inserted into a size .20 mm diameter canal, prepared by a 35/06 Segmented File, and extended the preparation an additional 3mm. The maximum torque generated was 14.3 gm-cm. This unusually low torque resulted because the amount of engagement was limited to the 3mm tapered portion of the instrument.

number of files need to be used and excessive stress on any of the files can easily be prevented. Having smaller maximum diameters, proportionally less cross-section areas per diameter, and smaller shafts, enhances the flexibility of the files for mid-root and apical preparations. The area of the working surface is limited and there is little difference between the minimum diameter and maximum diameter on each file. Consequently, the torque necessary to rotate the maximum diameter or the total working surface is not enough to cause failure in the tip portion of the file.

As an added advantage, the tapered working surface of each segmented file is followed by a parallel or reversed tapered shaft that may or may not be fluted; therefore, the smaller mid-root and coronal shaft diameters facilitate negotiating curvatures and reduce the tendency for straightening the canal. In using each file, the recommendation still follows that no additional pressure, greater than

the initial pressure that was required to advance the file into the canal, should be exceeded. In addition to reducing the blade engagement by shortening the working length, the blade design has been modified to minimize engagement, as well as enhance efficiency and flexibility, by using an asymmetrical 3-fluted H-type cross-section.

57. Are there any unconventional file design improvements possible while using conventional manufacturing techniques?

Historically, virtually all endodontic files of any significance have had spiraled fluted designs. Ever since the introduction of the Hedstrom file, the spiraled flutes of endodontic files have been fabricated by rotating a taped wire against a grinding wheel. Although the introduction of twisted NiTi rotary files is anticipated, most rotary files

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continue to be fabricated in this manner. The limitations for changing the angles of the grinding wheel while fluting the file as it transverse the file shaft restricts the number of features that can be incorporated in the file design.

An important manufacturing development is transverse grinding. Rather than grinding flutes that spiral around a shaft, notches are ground across the shaft. A working surface composed of notches ground at different angles and depths can result in an extensive assortment of designs each of which can be modified to address the demands of canal anatomy. The notches can have various geometric configurations which can result in multiple different cross sectional configurations along the length of the file. The depth of the notches can change

the flexibility and resistance to separation. Different angles of the notches can control the screwing-in factor, debris removal and cutting efficiency. The practicality and convenience for adapting the file design to its desired function has the potential for a substantial advance in file design and file manufacturing.

To reiterate the introduction of this chapter, the ultimate purpose of this book is to help provide the means to advance the development of new root canal preparation modalities. Since the clinician is the only one who has first-hand knowledge of what problems exists, with the framework of understanding provided in this book, he or she needs to personally become involved in the development of instruments or to guide manufacturers toward advancing improvements.

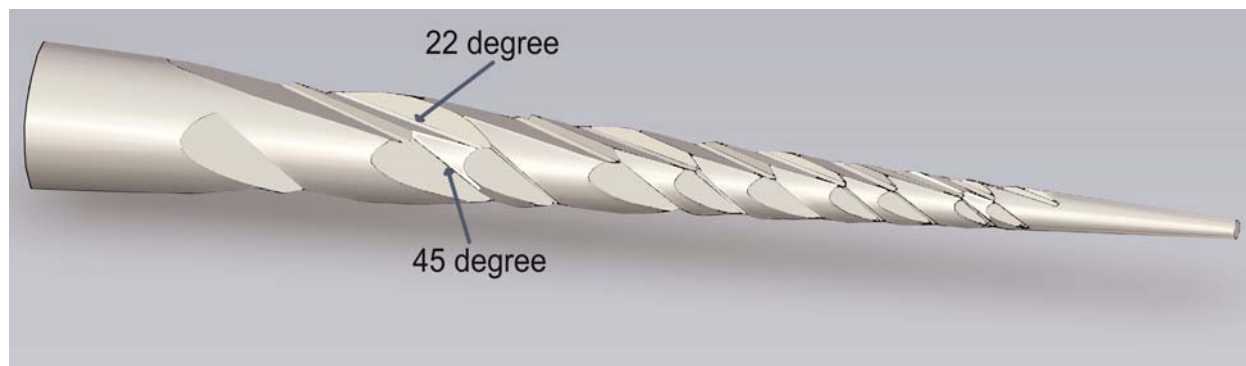


Fig. 146 Notches can have various geometric configurations and can be ground at various angles across the long axis of the file shaft.

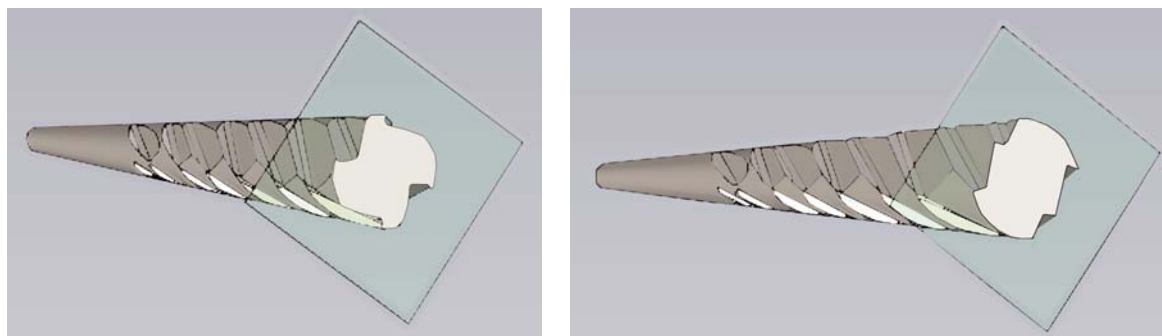


Fig. 147 The file can have multiple different cross sectional configurations along its length.

The research compiled for this book is recorded on a DVD for your convenience. Each evaluation can easily be copied or printed. The DVD can be found on the front cover.

Section V Mastering Research

Creating the appearance of the proof you want is easy; understanding the evidence is more difficult.

Research often appears to portray the advantages or disadvantages of files while the scope of investigation is too narrow for a conclusion as to the file's superiority or inferiority. Efficient files may not be able to accommodate as much stress as less efficient files but may require less stress to accomplish the same results. Efficient files may transport canals more per unit time but require less time to obtain the canal enlargement needed. Increasing flexibility will probably reduce resistance to torsion failure. These and other examples illustrate how considering one file characteristic without considering the relationship to other characteristics tell us little about the overall significance of a file design. The same can be said about techniques, i.e. the claim that fewer files can be used in a technique as an advantage, might actually subject each file to greater stress and the greater likelihood of failure.

Researchers should honor their obligation to present their findings in the context that any potential conclusion should be accompanied with its limitations, ramifications and practicalities related to their research. Research that does not address these issues should be considered incomplete or inconclusive. Often we reach a conclusion at the point we tire of examining.

As stated in the introduction, the purpose of this book is to provide the principles necessary for understanding the design of instruments and for developing the rationale necessary to use instruments to their greatest benefit in relation to the canal anatomy. I also stated that this book does not pretend to be an authoritative treatise to validate or invalidate the claims for instruments or techniques. Rather, the results of testing are presented as tools to promote understanding, investigation and development. I encourage re-evaluations using different protocols. Inconsistent results from different investigators might be seeds for discovery.

The accompanying research does accomplish the following:

1. Only computer generated protocols were used that are devoid of user variables or subjectivities.
2. A broad spectrum of instrument types was used.
3. A broad spectrum of protocols was used.
4. Standard deviations were calculated for each evaluation using the following formula:

$$s = \sqrt{\frac{1}{N-1} \sum_{i=1}^N (x_i - \bar{x})^2}$$

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The limitations of the accompanying research include the following:

1. Most evaluations included 12 trials. Some evaluations included fewer than 12 trials, particularly if the standard deviation was low.
 2. The instruments were randomly selected within no particular time period of manufacturing.
 3. User variables or preferences were not considered.
 4. Differences in the file material were not taken in consideration.
 5. For the sake of consistency, all testing was done in matched plastic simulated canals instead of real teeth. Even though the evaluations differed quantitatively for teeth and plastic, the comparative relationships were significantly predictable.
1. The scale of the x axis is adjusted to fit the graph. The amplitude should not be confused with amount.
 2. The scale used for pressure is different from the scale for torque and was used mostly to show its relationship to torsion.
 3. The highest maximum torque of all samples and the lowest maximum torque of all samples are positioned at the points of their particular recording, but are transposed to the illustrated example.
 4. If the instrument failed during the test it was noted on the graph.

How Do I read the graphs illustrating the results of testing?

All evaluations illustrated by line graphs used the computerized clinical simulator described in chapter 2 (fig.42). Each line graph is a specific example of the tests conducted rather than a composite of a particular series of tests. As a specific example, it may not necessarily be representative of the series of tests but does include the pertinent information of the other tests. Two examples (Table: 59 and Table: 38) illustrate features that should be observed. Features that should be noted in interpreting the results include the following:

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Table: 59

Insrtument: Profile GT Size: 70 Taper: 1.2

Protocol: (Sequence) First instrument used in crown down series.
The file was advanced 2 mm after contact.



Maximum Torque of Sample = 2.02 (scaled)/Actual = 6.5 g-cm

Highest maximum torque of all samples = 6.7 g-cm

Lowest maximum torque of all samples = 6.3 g-cm

Mean Torque = 6.5 g-cm

Maximum Pressure (scaled) = 2.01

Number of Samples = 12

Standard Deviation = 0.197

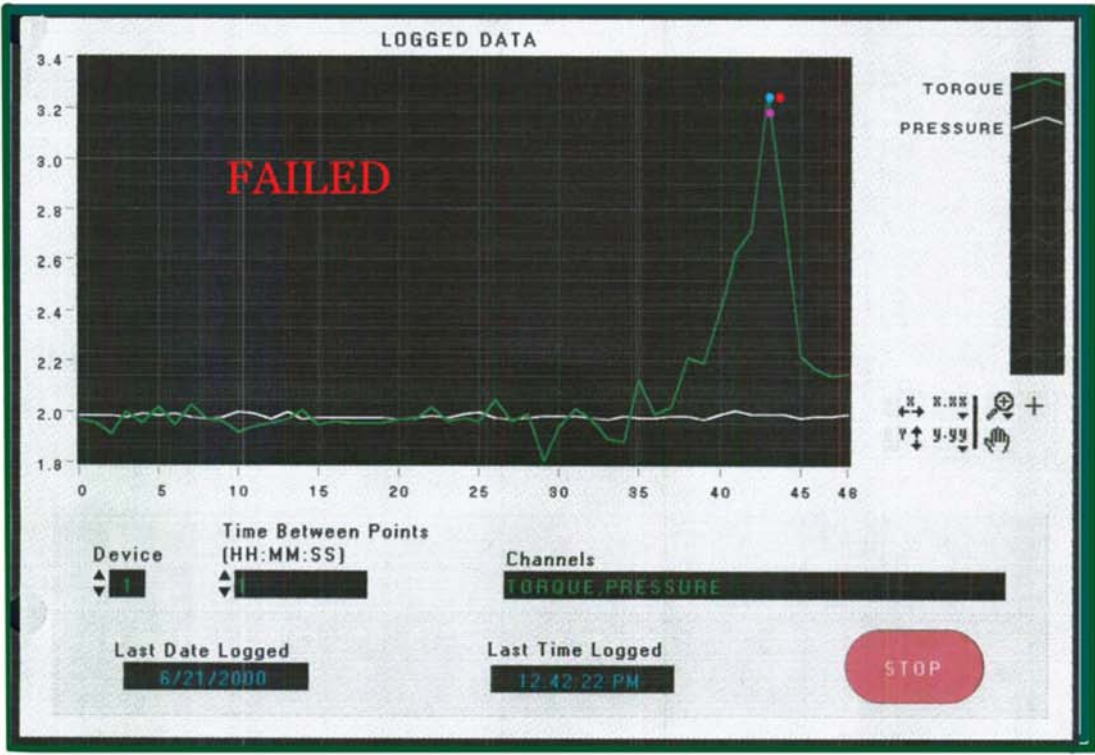
Sequence	Instruments						
	70/12	50/12	35/12	20/10	20/08	20/06	30/04
Depth (mm)	2	4	5	8	11	14	16
Insertion (mm/rep)	2	4	5	8	11	14	16
Rate (mm/sec)	1	1	1	1	1	1	1
Speed (rpm)	300	300	300	300	300	300	300

Fig. 147

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Table: 38
Insrtument: RaCe Size: 25 Taper: .08
Protocol: Single

After contact with the canal wall, the file was ad-
vanced 16 mm in 0.5 mm repetitions at a rate of 1 mm/sec to a depth
of 16 mm.



Maximum Torque of Sample = 3.52 (scaled)/Actual = 204g-cm
Highest maximum torque of all samples = 204 g-cm
Lowest maximum torque of all samples = 199 g-cm
Mean Torque = 202 g-cm
Maximum Pressure (scaled) = 2.0
Number of samples: 12
Standard deviation: 1.83

	Instrument
Sequence	FKG Race 19/08
Depth (mm)	16
Insertion (mm/rep)	0.5
Rate (mm/sec)	1
Speed (rpms)	500

Fig. 148

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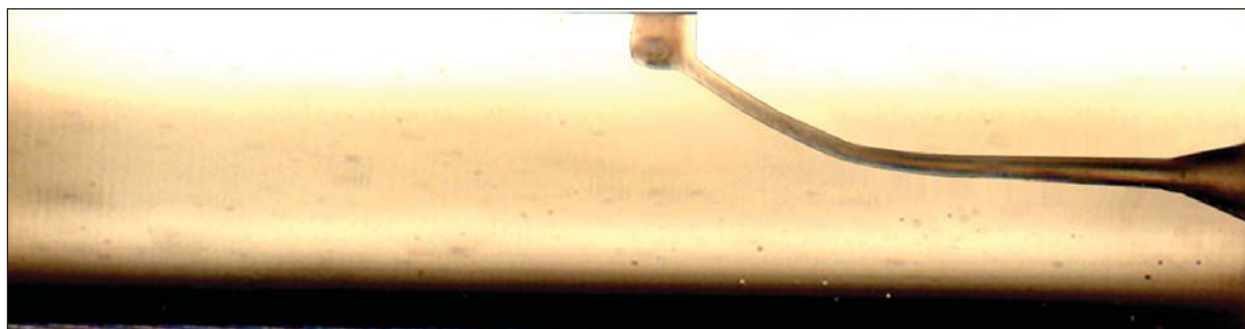
Inductive reasoning is based on the ability to generalize from repeated experiences or observations. The soundness of an inductive generalization can usually be determined by asking the following questions:

1. Do we have a sufficient number of instances to draw a conclusion?
2. Is the breadth of the conclusion drawn supported by the evidence?
3. Are the terms of the conclusion consistent with the terms of the evidence?

Fallacies result if any of these questions can be answered in the negative. Although I have conducted approximately 4,000 trials of carefully controlled protocols for testing endodontic rotary files, independent of operator variables, I am hesitant to draw conclusions for any series of files. I prefer to refer to observations during specific narrow circumstances while describing the consequences of rotating files. Conclusions would need a great deal of craftsmanship for incorporating the exceptions. I have selected 1,744 experimental trails (but

who is counting) for observation. These particular selections were made to illustrate some important differences. Hopefully you will recognize the evidence I used for writing "Mastering Endodontic Instrumentation." More importantly, you will discover apparent trends that will enable you to enhance your expertise.

Each of the trials was carried out in the simulated canals of plastic blocks matched for consistency. All evaluations illustrated by line graphs used the computerized clinical simulator described in chapter 2 (fig. 42). Each line graph is a specific example of the tests conducted rather than a composite of a particular series of tests. As a specific example, it may not necessarily be representative of the series of tests but does include the pertinent information of the other identical tests. Standard deviations were calculated from all the tests for the designated instrument with identical parameters.



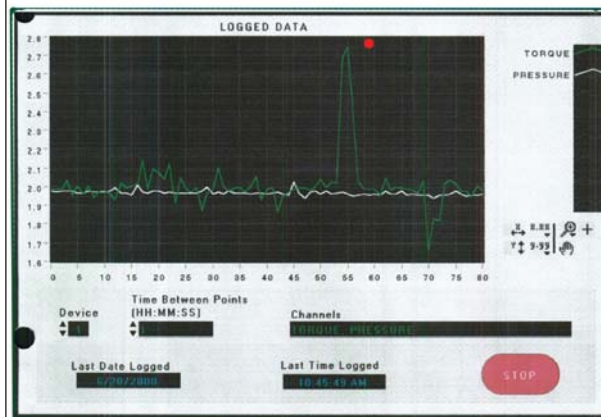
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Group 1. Profile files were advanced into a simulated canal in a plastic block at a rate of 1mm/s with one continuous insertion at a rotation speed of 250rpm to a depth of 16mm.

Table: 1 (12)

Insrtument: Profile Size: 15 Taper: .04

Protocol: Advancement into canal



Maximum Torque of Sample = 2.75 (scaled)/Actual 400.1 g-cm

Highest maximum torque of all samples = 104.2 g-cm ●

Lowest maximum torque of all samples = 12.1 g-cm

Mean Torque = g-cm

Maximum Pressure (scaled) =

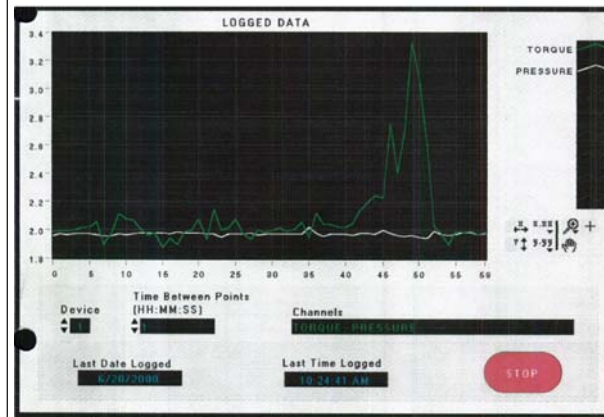
Number of Samples = 12
Standard Deviation = 33.1

Depth (mm)	16
Insertion (mm/rep)	1
Rate (mm/sec)	1
Speed (rpms)	250

Table: 2

Insrtument: Profile Size: 20 Taper: .04

Protocol: Advancement into canal



Maximum Torque of Sample = 3.43 (scaled)/Actual = 192.4 g-cm

Highest maximum torque of all samples = 224.2 g-cm

Lowest maximum torque of all samples = 169.3 g-cm

Mean Torque = g-cm

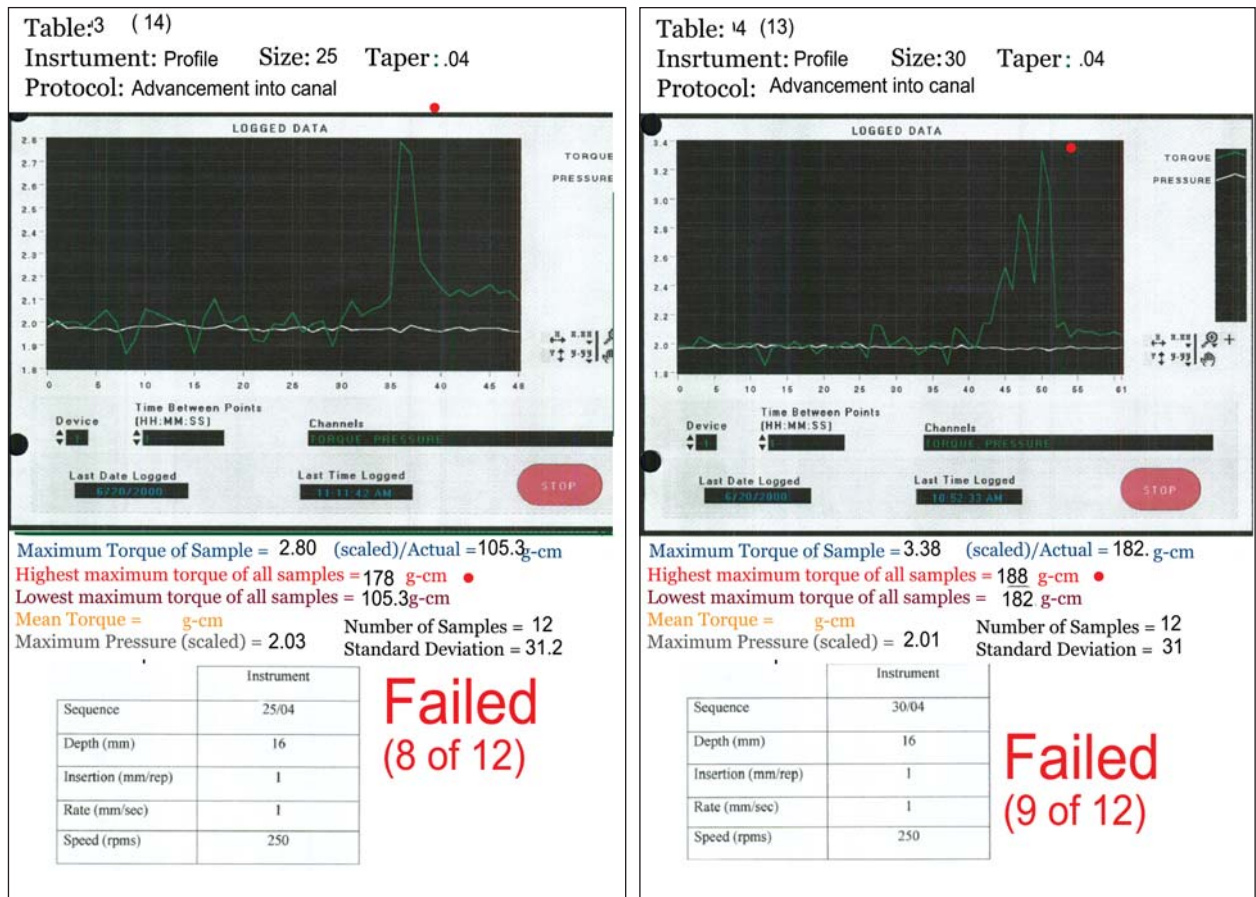
Maximum Pressure (scaled) = 2.02

Number of Samples = 12
Standard Deviation = 96.9

Instrument	
Sequence	20/04
Depth (mm)	16
Insertion (mm/rep)	1
Rate (mm/sec)	1
Speed (rpms)	250

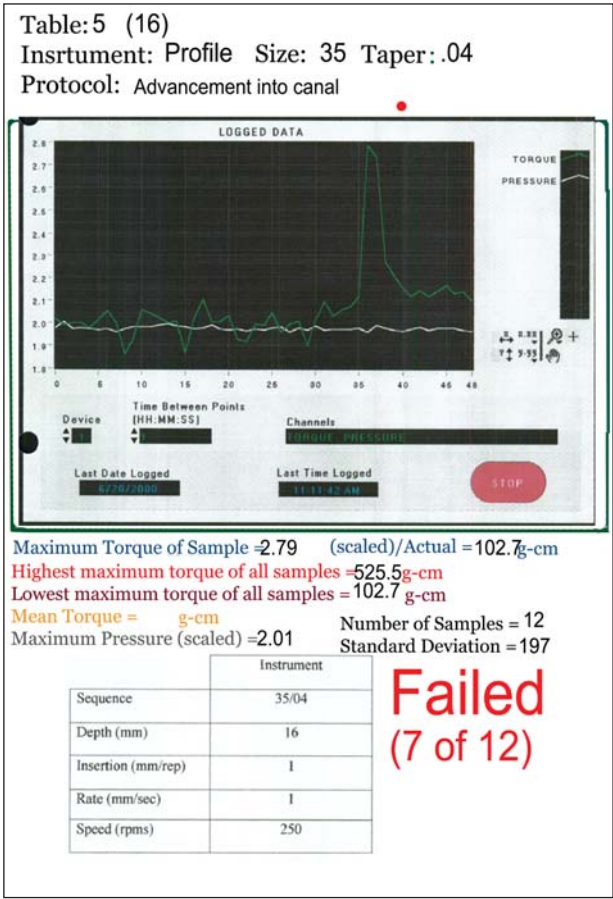
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Group 1 continued. Profile files were advanced into a simulated canal in a plastic block at a rate of 1mm/s with one continuous insertion at a rotation speed of 250rpm to a depth of 16mm.



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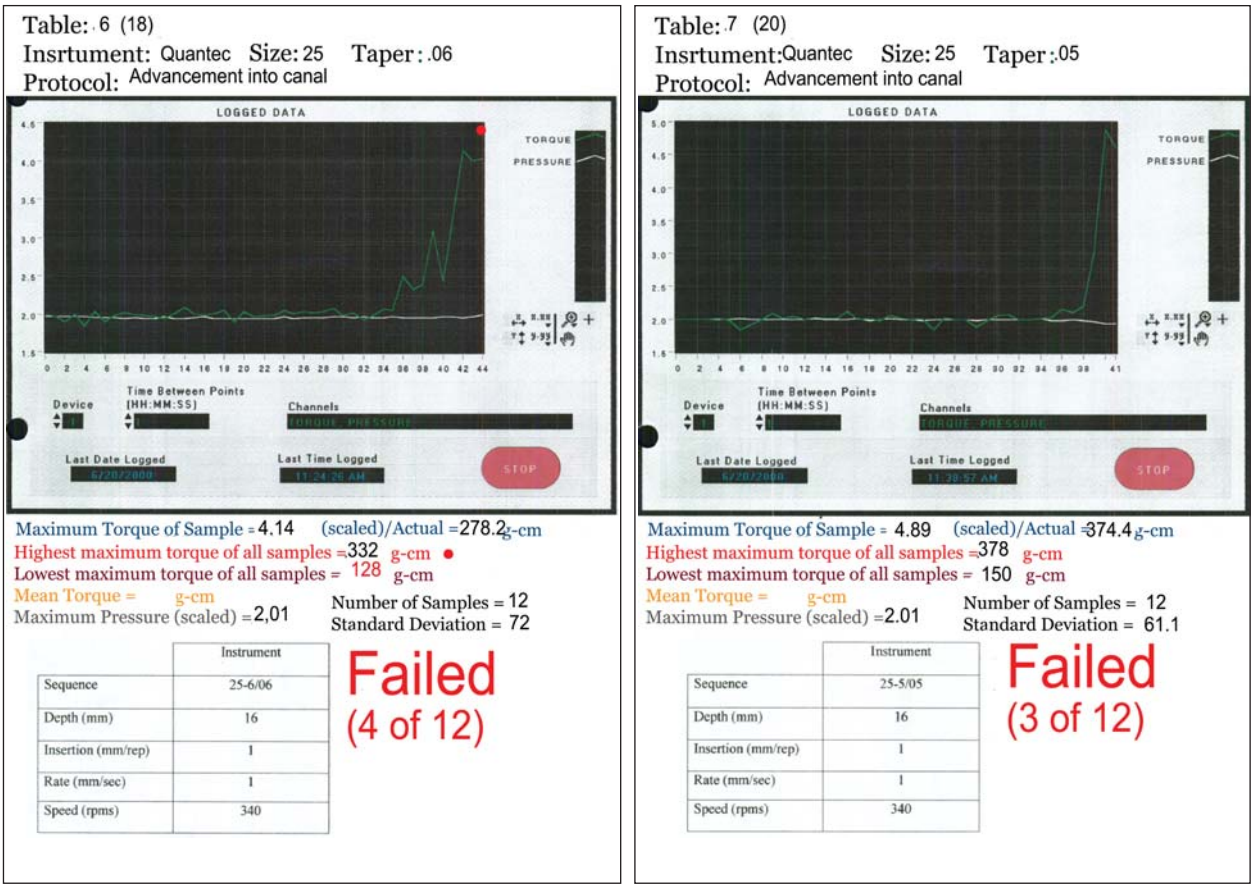
Group 1 continued. Profile files were advanced into a simulated canal in a plastic block at a rate of 1mm/s with one continuous insertion at a rotation speed of 250rpm to a depth of 16mm.



As an observation of Group 1 and the groups that follow, note where the spikes representing torsion stress occurred In the case of Group1 series torsion stress spikes occurred in the second one half of the time segment. Prevention of failure is paramount. Had the advancement into the canals been terminated after 6mm all failures would have been prevented for these particular evaluations. This is the reason for instrumentation consideration on page 105 of section 3 of the text: 6. Except for .02 tapered files having a size diameter of .20mm and smaller, do not engage more than 6 mm of the file’s working surface if the file is engaged in a curvature.

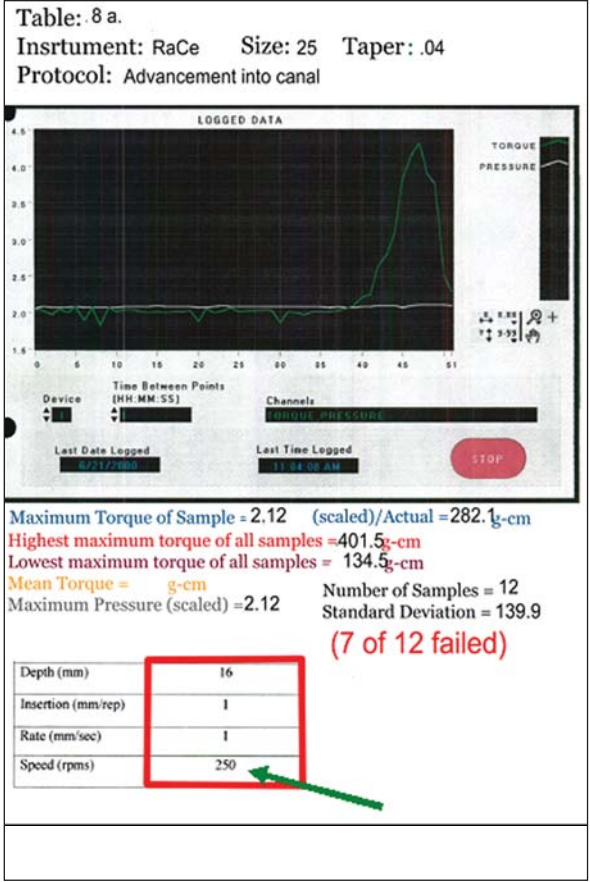
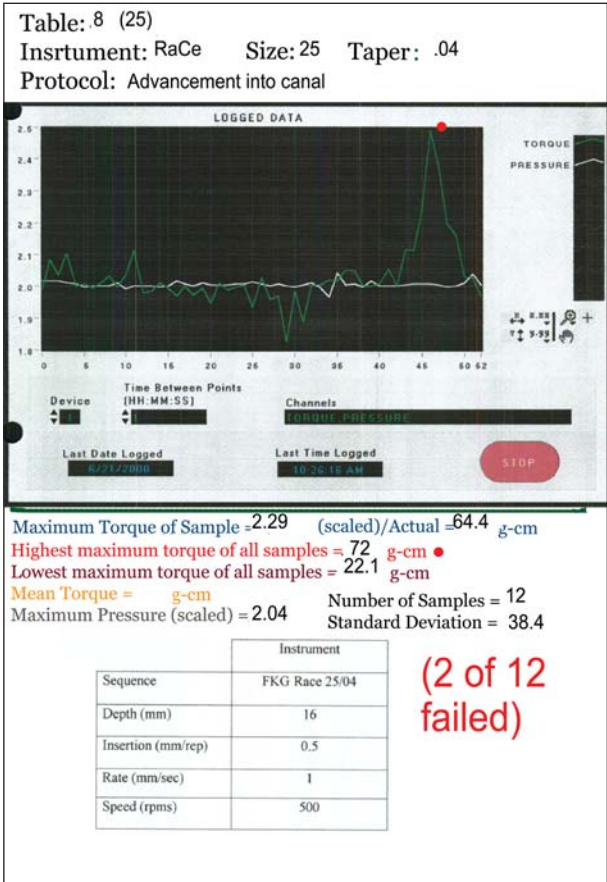
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Group 2. Quantec files were advanced into a simulated canal in a plastic block at a rate of 1mm/s with 1mm insertion repetitions at rotation speed of 340rpm to a depth of 16mm.



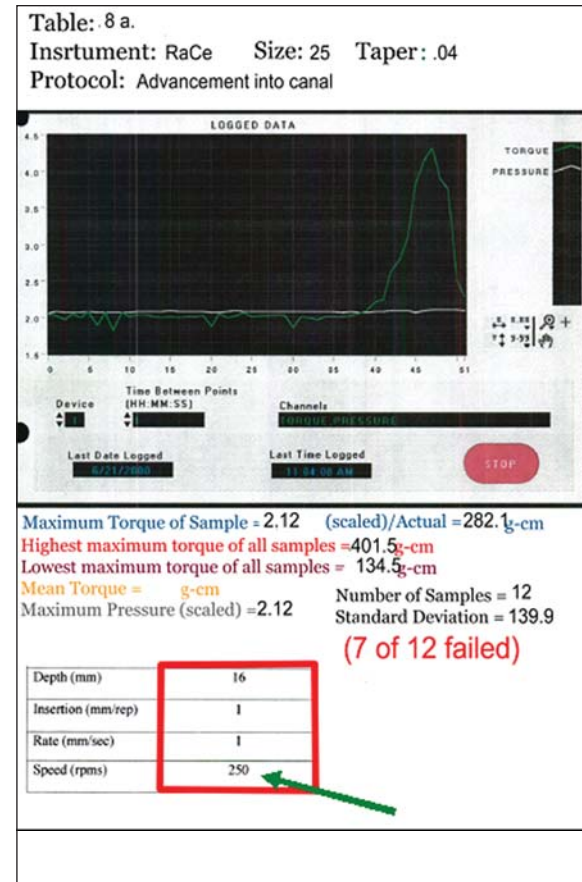
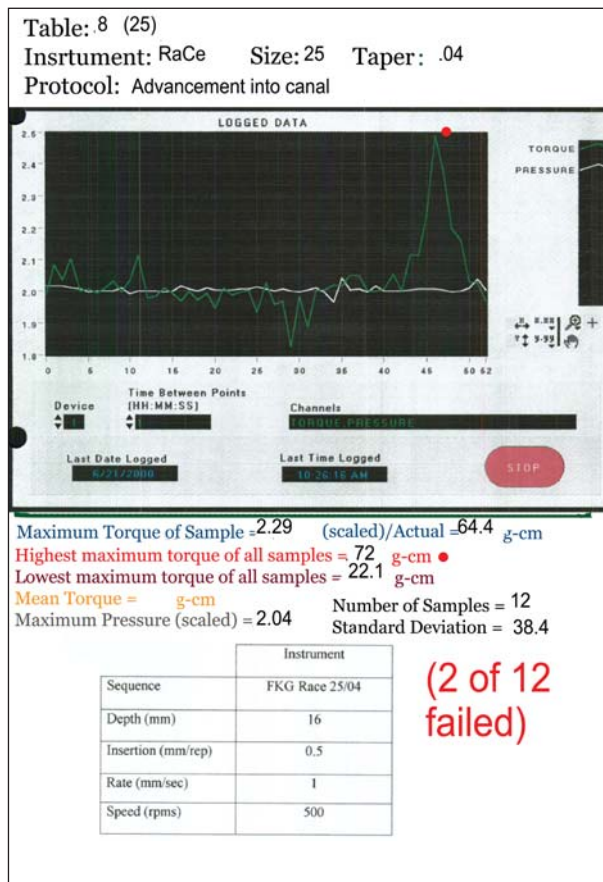
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Group 3. RaCe files were advanced into a simulated canal in a plastic block at a rate of 1mm/s with 0.5mm insertion repetitions at rotation speed of 500rpm to a depth of 16mm. (Table 8a. When the speed was reduced and the depth of insertion was increased failure increased. Refer to p. 36 design consideration number 8. The RaCe file has fewer spirals that require greater speeds of rotation.)



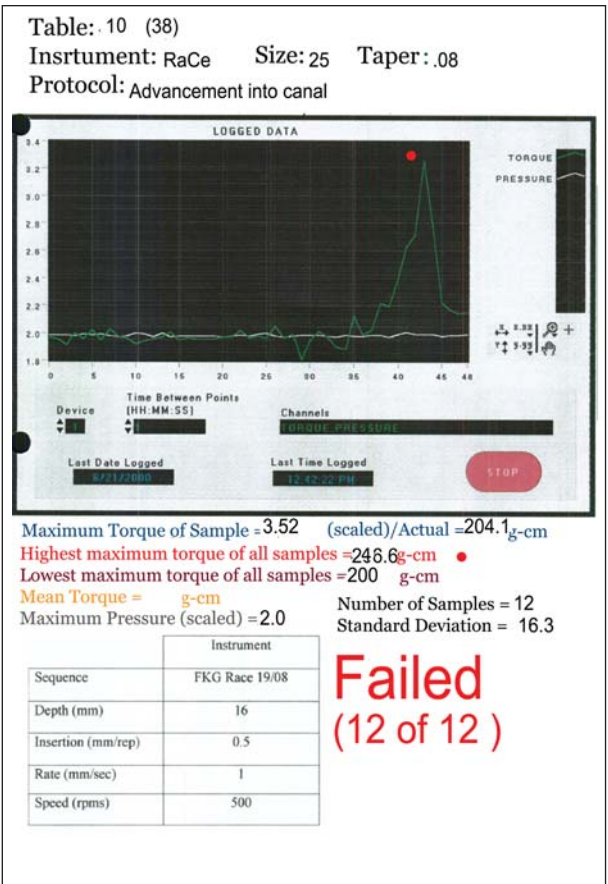
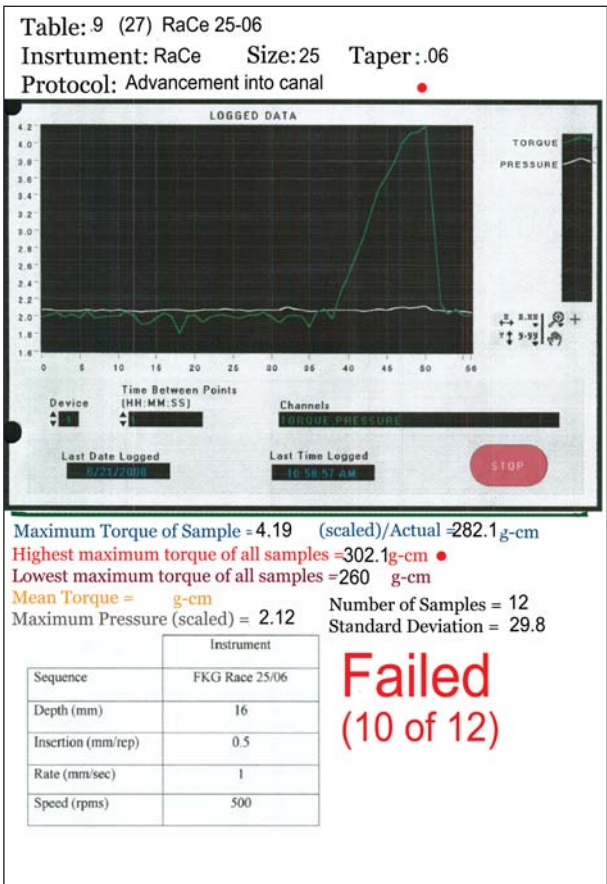
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Group 3. continued. RaCe files were advanced into a simulated canal in a plastic block at a rate of 1mm/s with 0.5mm insertion repetitions at rotation speed of 500rpm to a depth of 16mm. (Note that failure increases as the surface area of the file increases.)



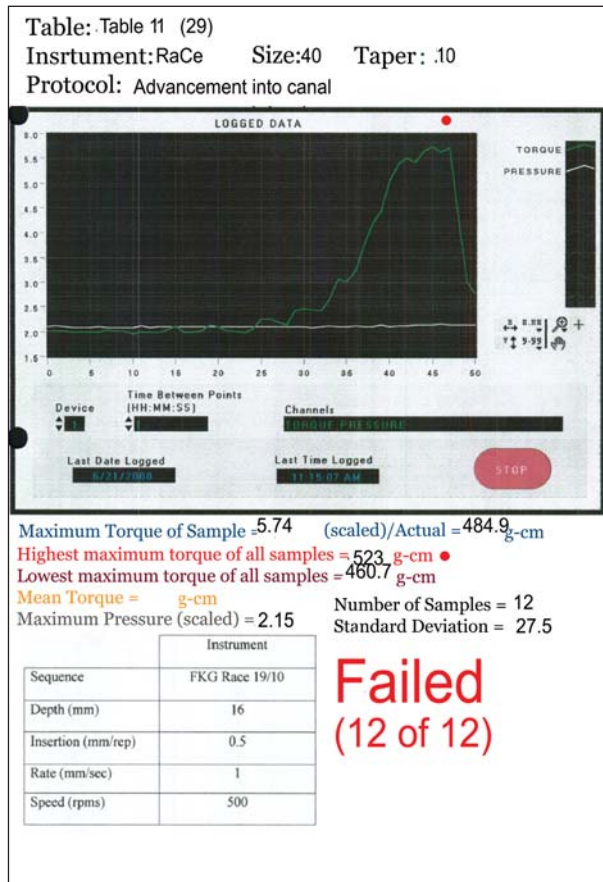
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Group 3. continued. RaCe files were advanced into a simulated canal in a plastic block at a rate of 1mm/s with 0.5mm insertion repetitions at rotation speed of 500rpm to a depth of 16mm. (Note that failure increases as the surface area of the file increases.)



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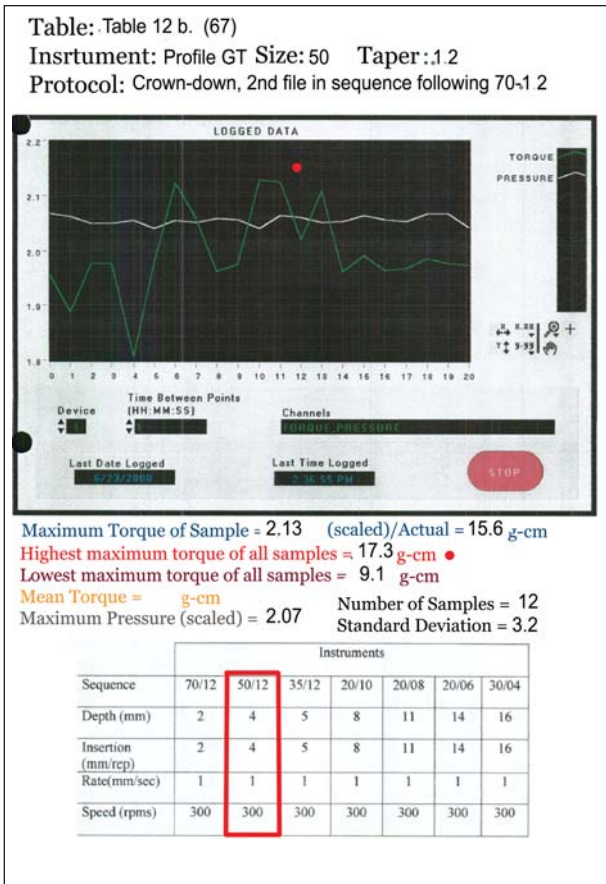
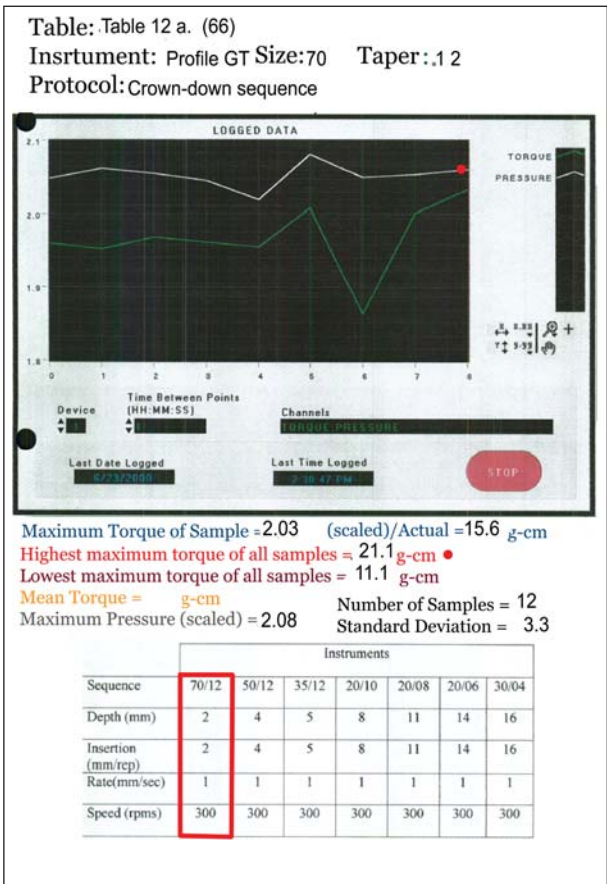
Group 3. continued. RaCe files were advanced into a simulated canal in a plastic block at a rate of 1mm/s with 0.5mm insertion repetitions at rotation speed of 500rpm to a depth of 16mm. (Note that failure increases as the surface area of the file increases.)



Note that each instrument in Group 3. enlarged canals having the same dimensions. Also note that torsion stress increases with an increase of the surface area of the file engagement. Surface area increases with an increase in the depth of engagement, the file tip diameter, and the file taper. In addition to total file engagement, torsion stress is caused by the formation and dislodgement of chips, abrasion of any file surface rotating against the canal wall, compression of debris, and distortion of the file which results from rotating in a curvature.

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Group 4 In a Crown-down sequence, each **Profile GT** file preceded or followed another Profile GT file in a series and advanced into a simulated canal in a plastic block at a rate of 1mm/s with 1 continuous insertion to a designated depth. at rotation speed of 300rpm.



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Group 4 continued. In a Crown-down sequence, each **Profile GT** file preceded or followed another Profile GT file in a series and advanced into a simulated canal in a plastic block at a rate of 1mm/s with 1 continuous insertion to a designated depth. at rotation speed of 300rpm.

Table: 12 c.
Instrument: Profile GT Size: 35 Taper: 1.2
Protocol: Crown-down sequence, 35-1.2 following 50-1.2



Maximum Torque of Sample = 2.14 (scaled)/Actual = 23.4 g-cm
Highest maximum torque of all samples = 27.3 g-cm
Lowest maximum torque of all samples = 22 g-cm
Mean Torque = g-cm 2.07 Number of Samples = 12
Maximum Pressure (scaled) = Standard Deviation = 3.2

Sequence	Instruments						
	70/12	50/12	35/12	20/10	20/08	20/06	30/04
Depth (mm)	2	4	5	8	11	14	16
Insertion (mm/rep)	2	4	5	8	11	14	16
Rate(mm/sec)	1	1	1	1	1	1	1
Speed (rpms)	300	300	300	300	300	300	300

Table: 12 d. (62)
Instrument: Profile GT Size: 20 Taper: 1.0
Protocol: Crown-down sequence. Extends the prep of the 35-1.2

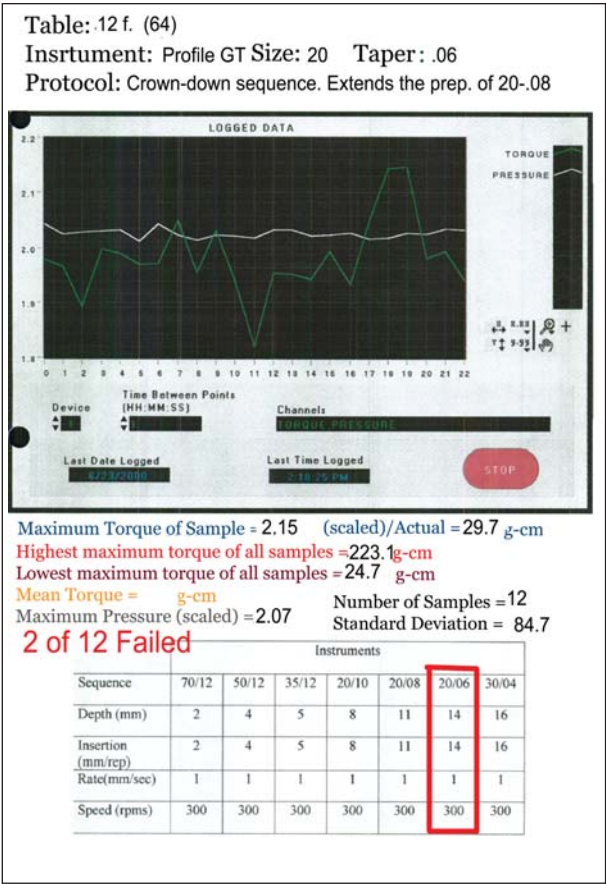
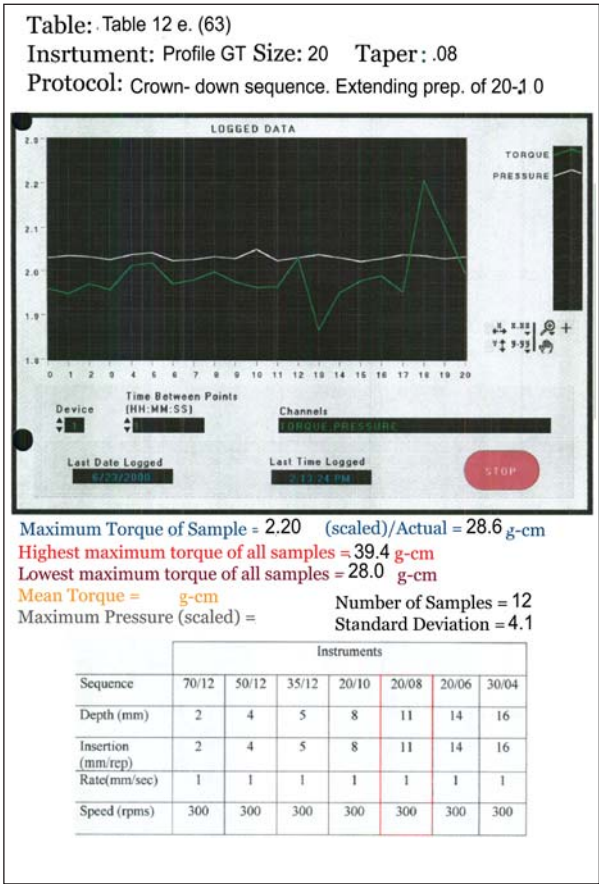


Maximum Torque of Sample = 2.07 (scaled)/Actual = 23.4 g-cm
Highest maximum torque of all samples = 32.6 g-cm
Lowest maximum torque of all samples = 11.3 g-cm
Mean Torque = g-cm Number of Samples = 12
Maximum Pressure (scaled) = Standard Deviation = 4.7

Sequence	Instruments						
	70/12	50/12	35/12	20/10	20/08	20/06	30/04
Depth (mm)	2	4	5	8	11	14	16
Insertion (mm/rep)	2	4	5	8	11	14	16
Rate(mm/sec)	1	1	1	1	1	1	1
Speed (rpms)	300	300	300	300	300	300	300

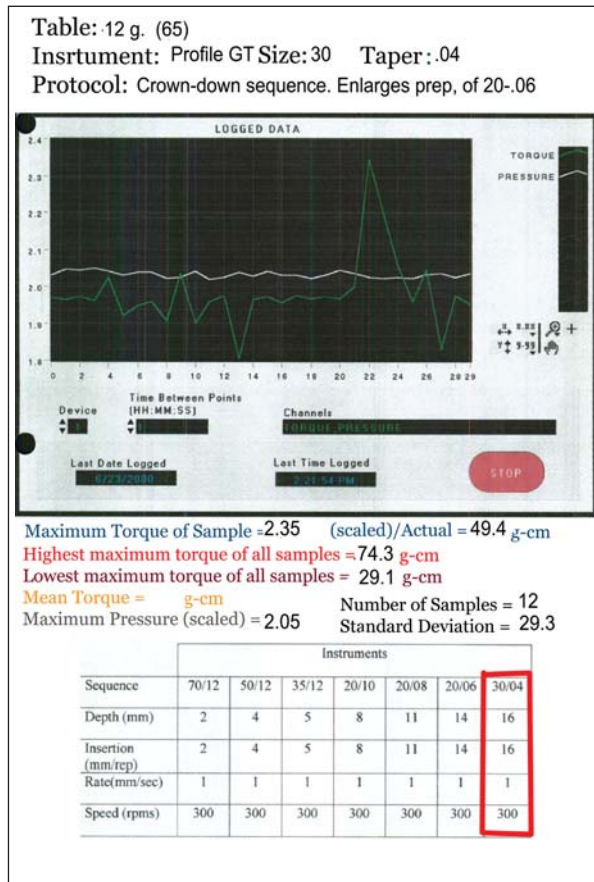
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Group 4 continued. In a Crown-down sequence, each **Profile GT** file preceded or followed another Profile GT file in a series and advanced into a simulated canal in a plastic block at a rate of 1mm/s with 1 continuous insertion to a designated depth. at rotation speed of 300rpm.



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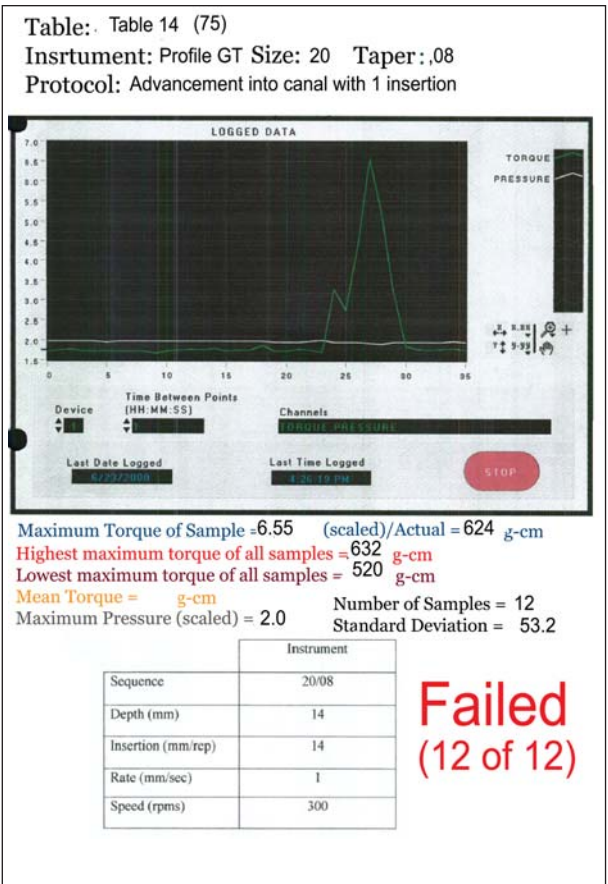
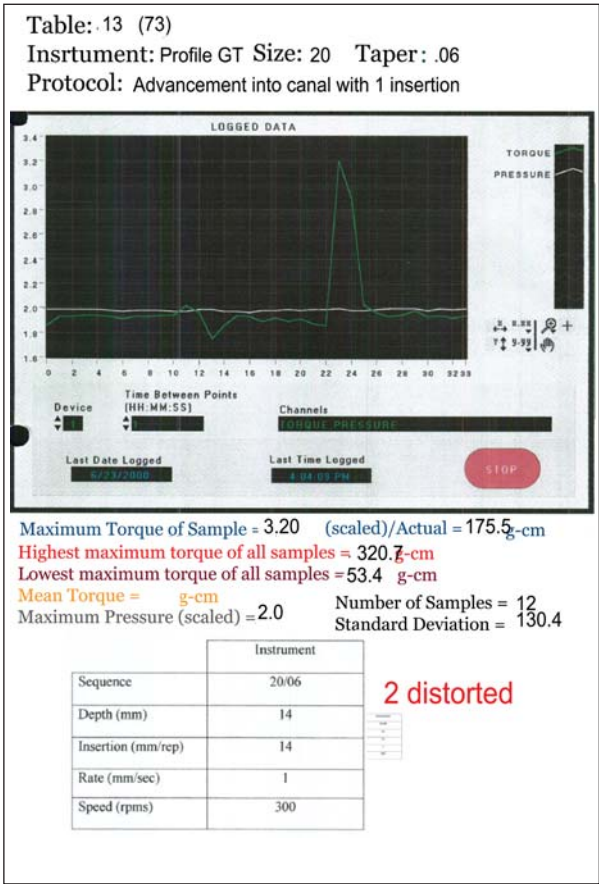
Group 4 continued. In a Crown-down sequence, each **Profile GT** file preceded or followed another Profile GT file in a series and advanced into a simulated canal in a plastic block at a rate of 1mm/s with 1 continuous insertion to a designated depth. at rotation speed of 300rpm.



Note that the 30/.04 Profile GT in Table 12g. advanced to a greater depth than the 20/.06 Profile GT in Table 12f. However, the 20/.06 advanced 3 mm whereas the 30/.04 advanced 2 mm. Refer to instrumentation consideration number 5 on page 105: If a file has more than a .02 taper, do not advance more than 2 mm beyond the preparation of the previous file if any part of the file is engaged in a curvature.

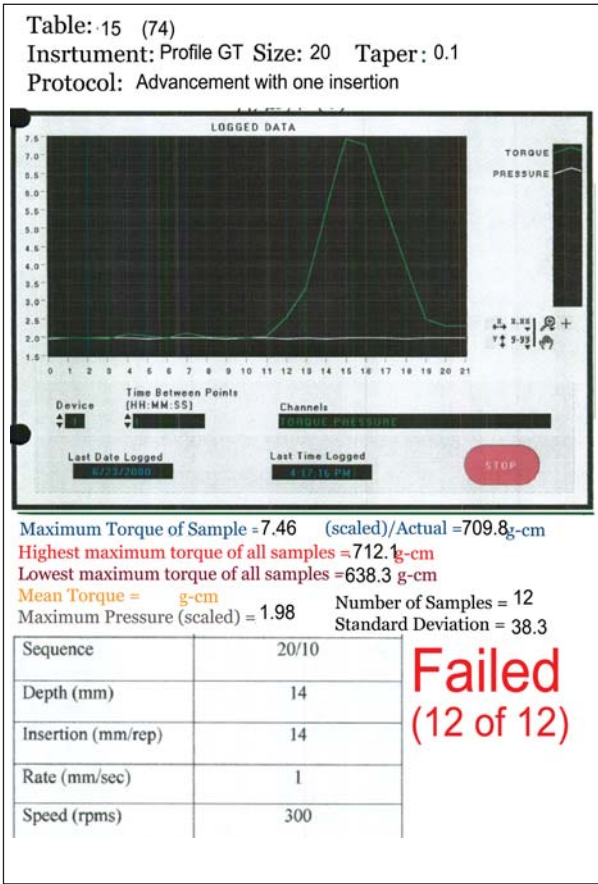
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Group 5. Profile GT file advanced into a simulated canal in a plastic block at a rate of 1mm/s with 1 continuous insertion to a 14mm depth. at rotation speed of 300rpm.



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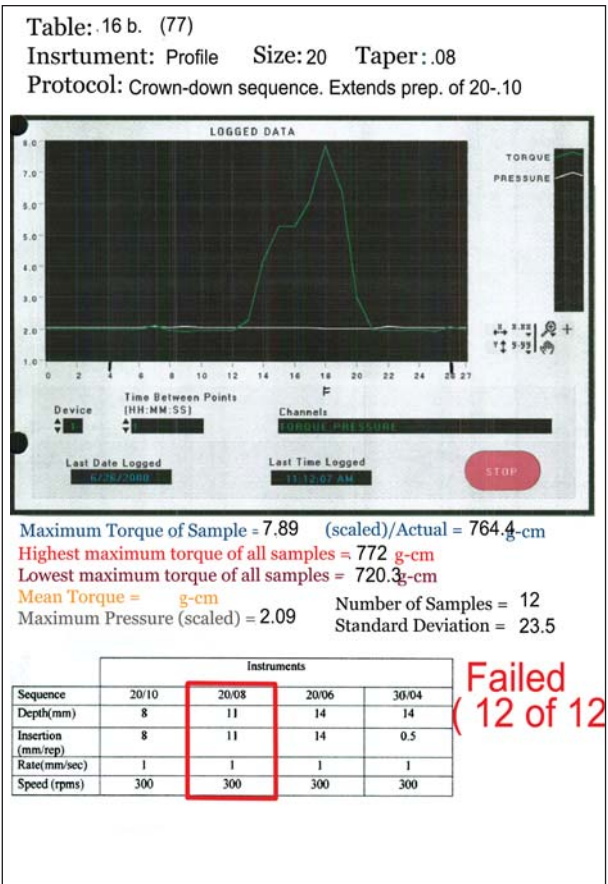
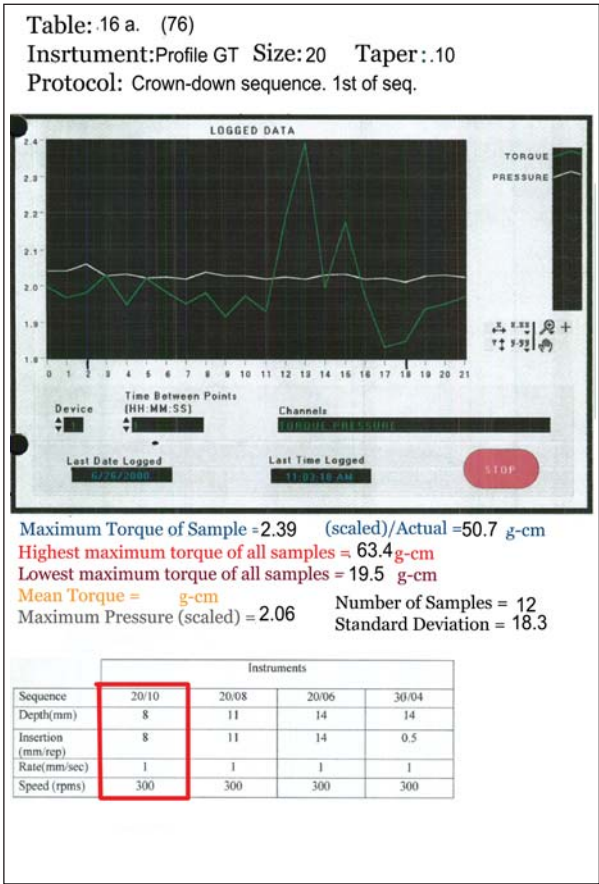
Group 5 continued. Profile GT file advanced into a simulated canal in a plastic block at a rate of 1mm/s with 1 continuous insertion to a 14mm depth. at rotation speed of 300rpm.



Note that at a 14 mm depth each file had advanced into 4mm of a curvature and each had violated more than one of the instrumentation considerations on page 105. None of the files began to fail until after 6mm of the working surface had become engaged (the last one half time segment of the insertion). Note that the 20/.08 and the 20/0.1 all failed when consideration number 8 was violated: Beyond the point of curvature in the apical zone, the file diameter should be no greater than .60mm for a .02 taper, .55mm for .04 taper, .50 for .06 taper, and .35 for a .08 taper.

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Group 6 In a Crown-down sequence, each **Profile GT** file preceded or followed another Profile GT file in a series and advanced into a simulated canal in a plastic block at a rate of 1mm/s with 1 continuous insertion to a designated depth. at rotation speed of 300rpm.



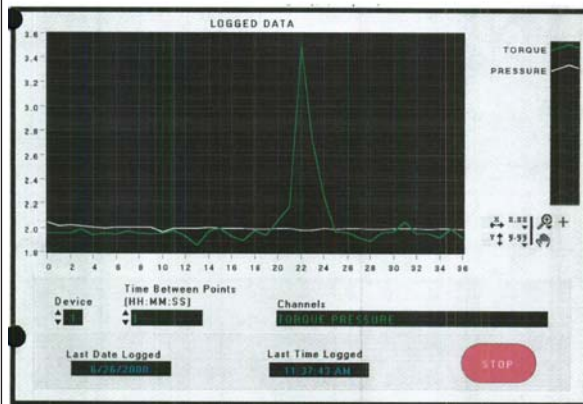
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Group 6 continued. In a Crown-down sequence, each **Profile GT** file preceded or followed another Profile GT file in a series and advanced into a simulated canal in a plastic block at a rate of 1mm/s with 1 continuous insertion to a designated depth. at rotation speed of 300rpm. (Note the difference that pre-flaring made when comparing the 20/.06 in Group 6 with the 20/.06 in Group 4 carried to the same depth.)

Table: 16 c.

Insrtument: Profile GT Size: 20 Taper: .06

Protocol: Crown-down sequence. Extends the prep. of the 20-.08



Maximum Torque of Sample = 3.50 (scaled)/Actual = 201.5g-cm
Highest maximum torque of all samples = 490.1g-cm (4 of 12 failed)
Lowest maximum torque of all samples = 200.0 g-cm
Mean Torque = g-cm
Maximum Pressure (scaled) = 2.05 Number of Samples = 12
Standard Deviation = 119.4

Sequence	Instruments			
	20/10	20/08	20/06	30/04
Depth(mm)	8	11	14	14
Insertion (mm/rep)	8	11	14	0.5
Rate(mm/sec)	1	1	1	1
Speed (rpms)	300	300	300	300

Table: 16 d, (130)

Insrtument: Profile GT Size: 30 Taper: .04

Protocol: Crown-down sequence. Final enlargement

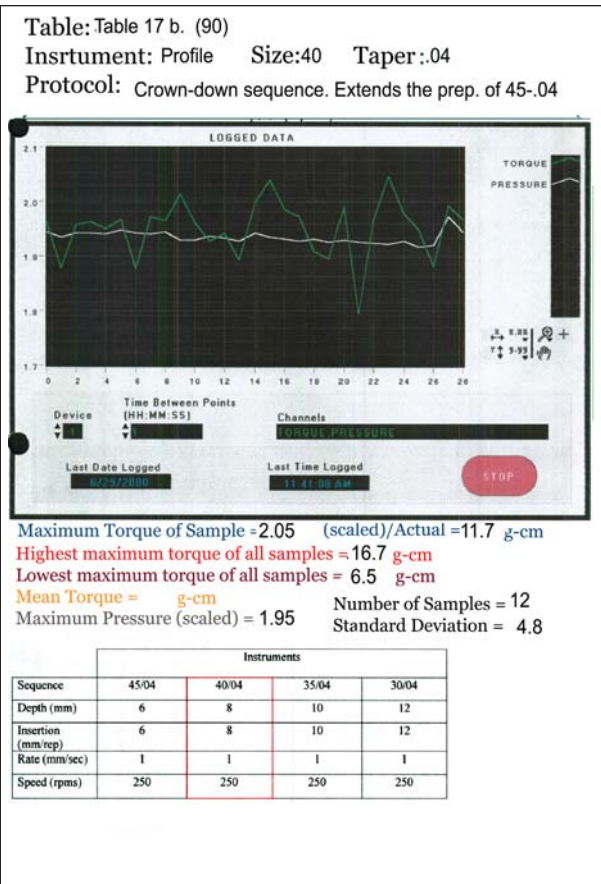
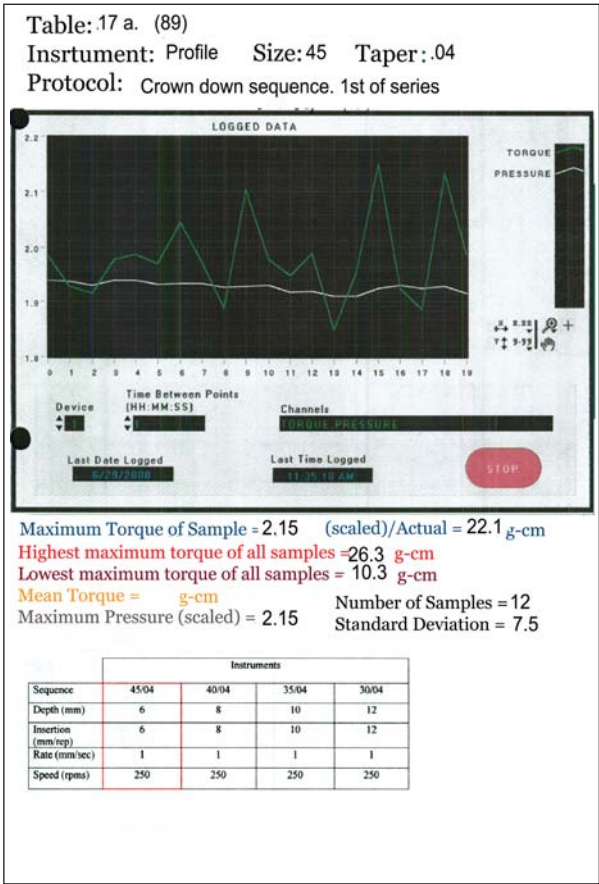


Maximum Torque of Sample = 2.13 (scaled)/Actual = 22.1 g-cm
Highest maximum torque of all samples = 28.9g-cm
Lowest maximum torque of all samples = 20.8 g-cm
Mean Torque = g-cm
Maximum Pressure (scaled) = 1.98 Number of Samples = 12
Standard Deviation = 3.8

Sequence	Instruments			
	20/10	20/08	20/06	30/04
Depth(mm)	8	11	14	14
Insertion (mm/rep)	8	11	14	0.5
Rate(mm/sec)	1	1	1	1
Speed (rpms)	300	300	300	300

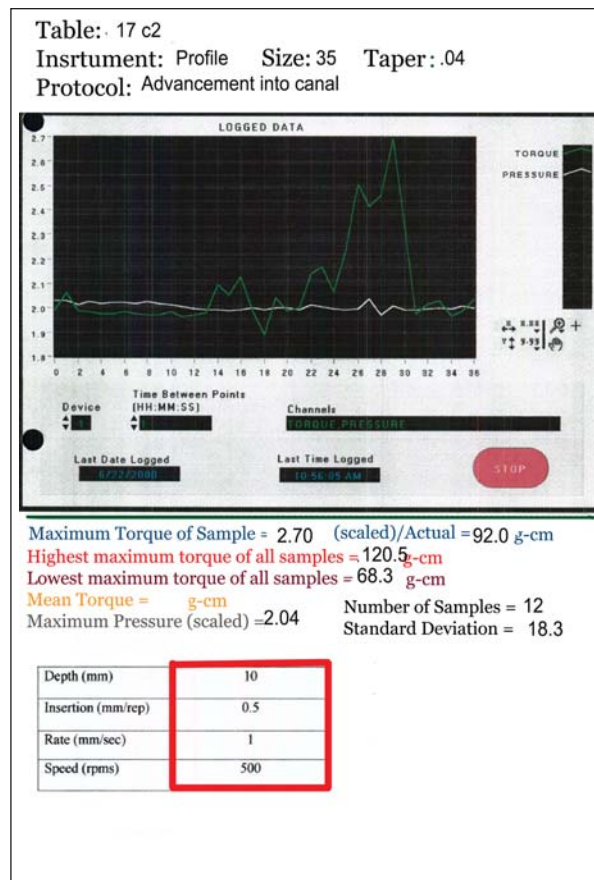
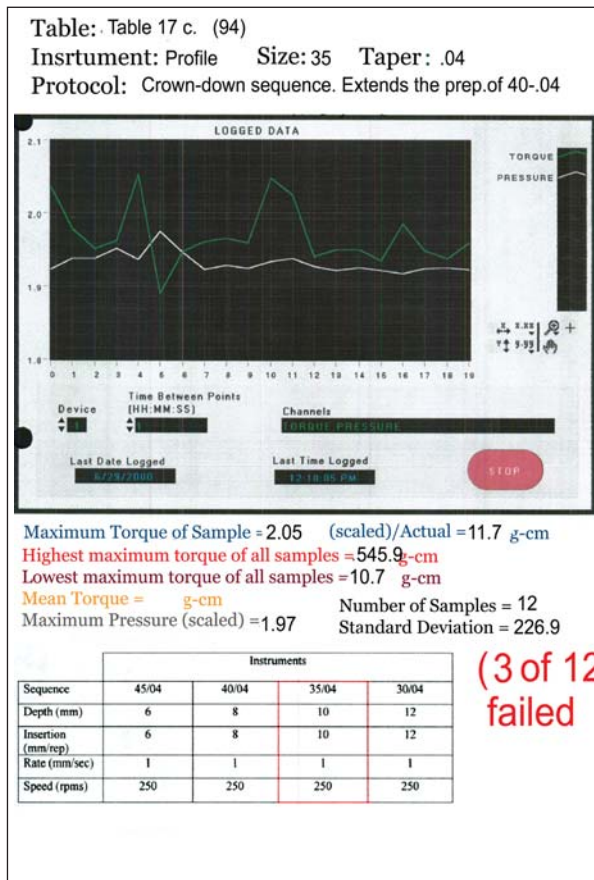
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Group 7 In a Crown-down sequence, each **Profile** file preceded or followed another Profile file in a series and advanced into a simulated canal in a plastic block at a rate of 1mm/s with 1 continuous insertion to a designated depth. at rotation speed of 300rpm.



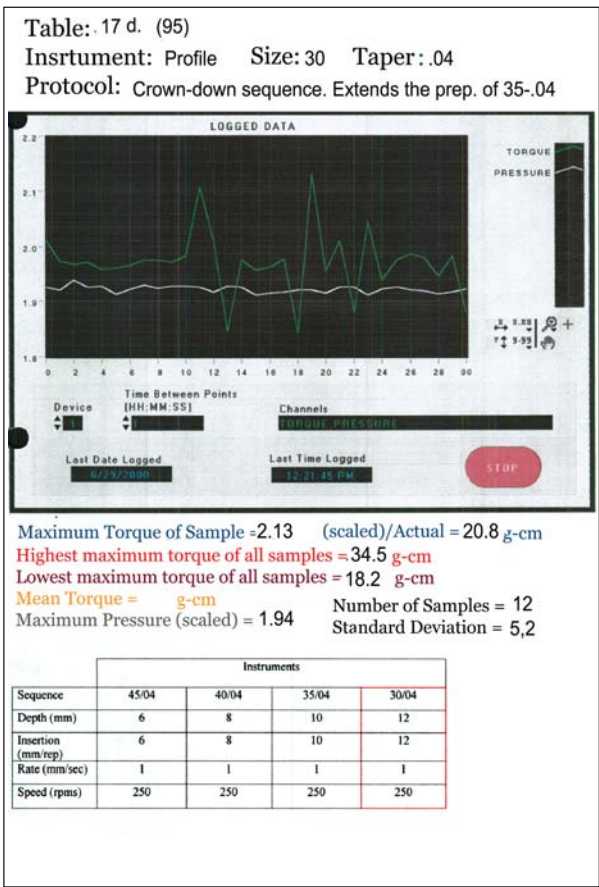
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Group 7 continued. In a Crown-down sequence, each **Profile** file preceded or followed another Profile file in a series and advanced into a simulated canal in a plastic block at a rate of 1mm/s with 1 continuous insertion to a designated depth. at rotation speed of 300rpm.



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Group 7 continued. In a Crown-down sequence, each **Profile** file preceded or followed another Profile file in a series and advanced into a simulated canal in a plastic block at a rate of 1mm/s with 1 continuous insertion to a designated depth. at rotation speed of 300rpm.

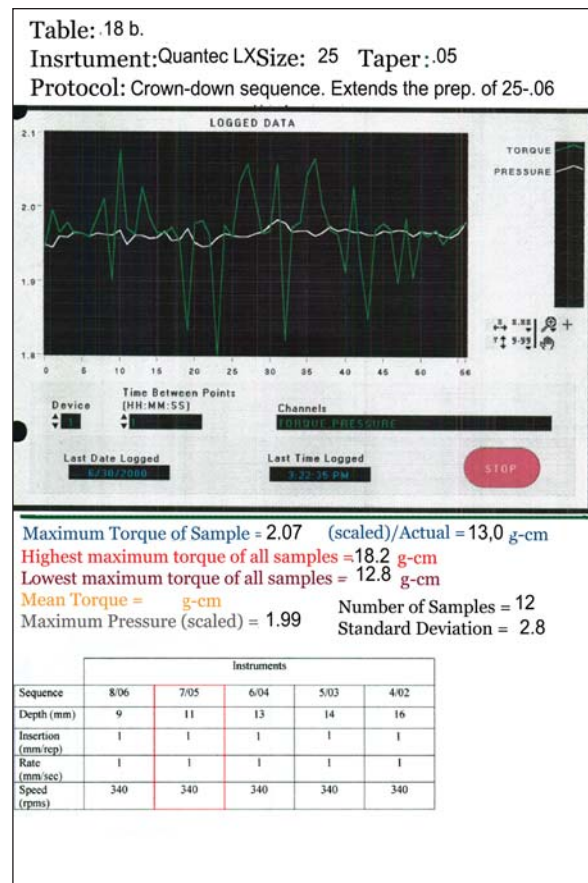
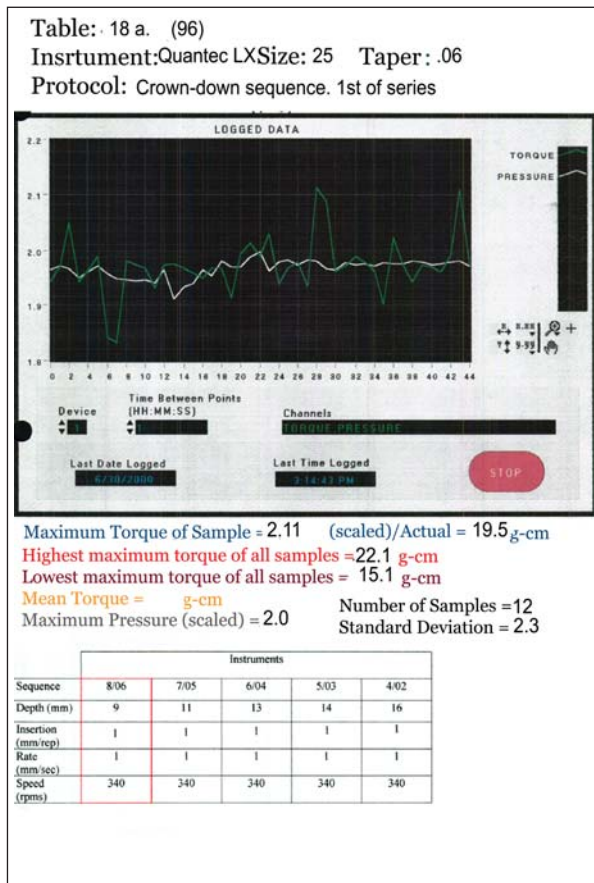


Note that the 35/.04 file in Table 17c. extend-
ed the preparation only 2mm but did so in
one continuous insertion and had a propen-
sity for failure. The 35/.04 file in Table 17c2.
extended the preparation 2mm but did so
with 0.5 insertions and no failures occurred.
Refer to number 2 of instrumentation consid-
erations on page 105:

*Advance the file into the canal with no more
than 1mm increments with insert/with-
draw motions.*

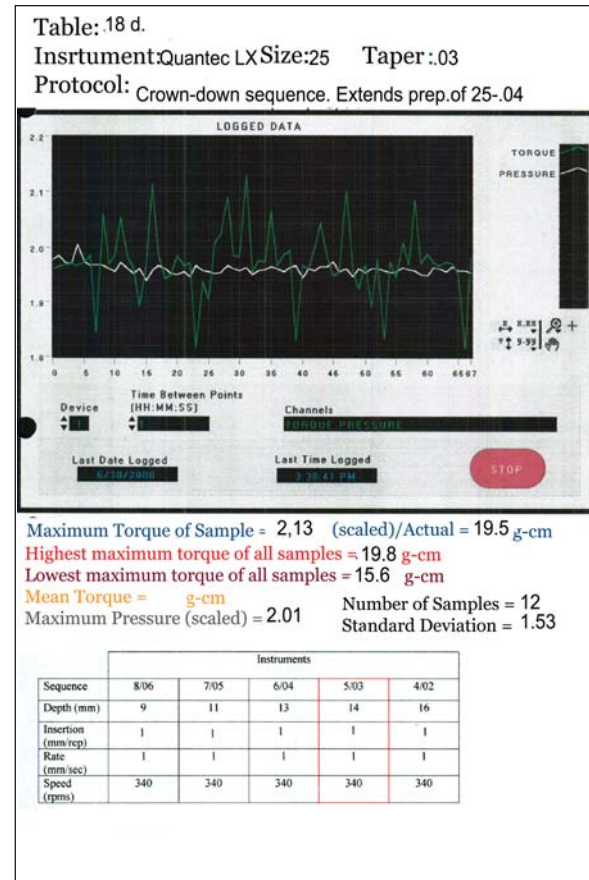
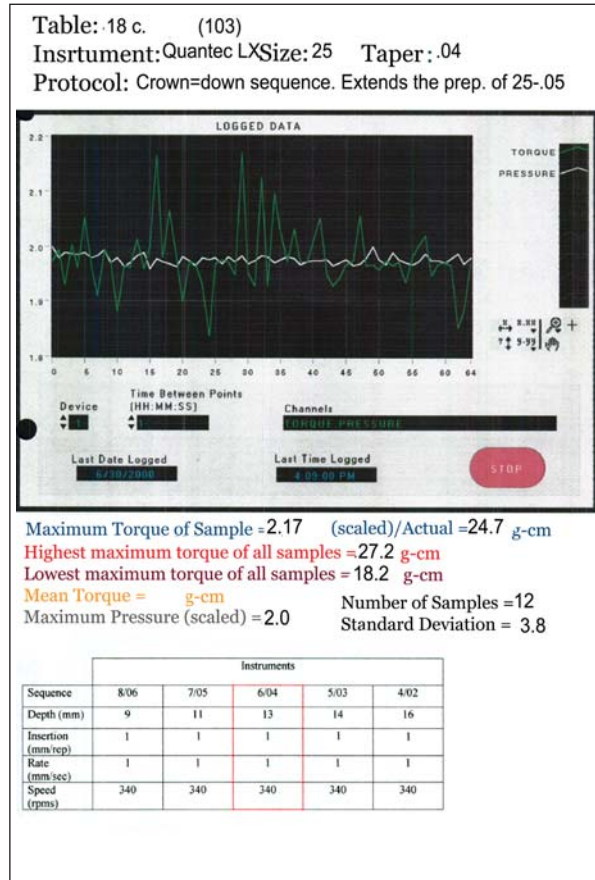
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Group 8 In a Crown-down sequence, each **Quantec** file preceded or followed another Quantec file in a series and advanced into a simulated canal in a plastic block at a rate of 1mm/s with 1mm insertion increments to a designated depth. at rotation speed of 340rpm.



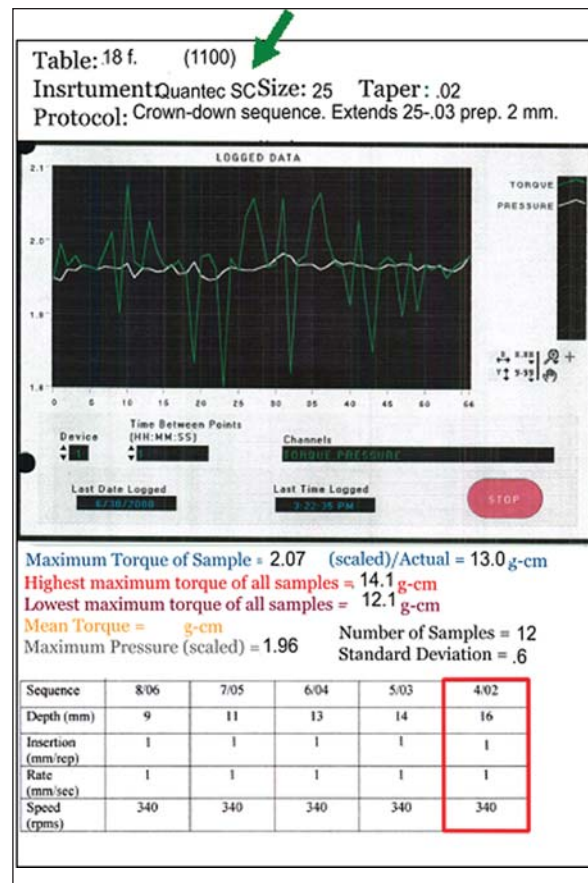
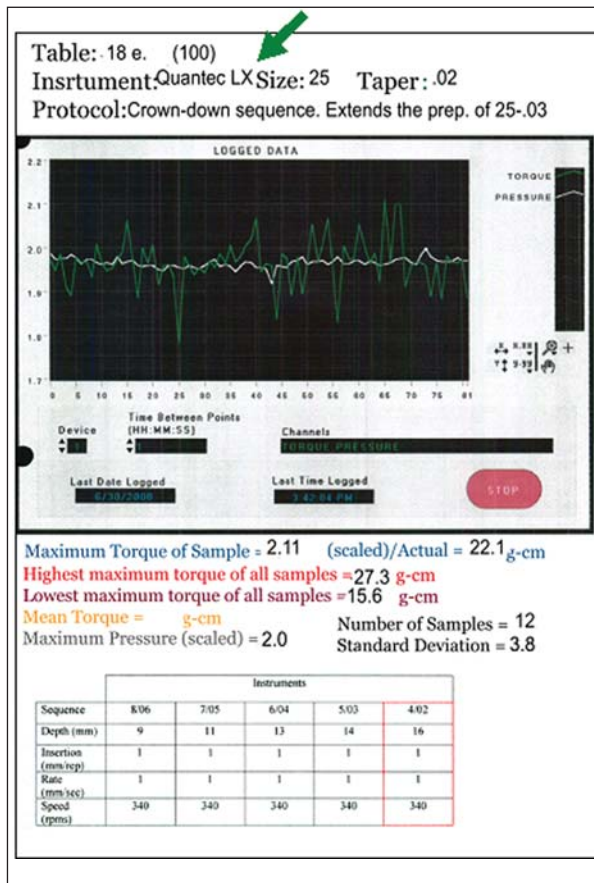
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Group 8 continued. In a Crown-down sequence, each **Quantec** file preceded or followed another Quantec file in a series and advanced into a simulated canal in a plastic block at a rate of 1mm/s with 1mm insertion increments to a designated depth. at rotation speed of 340rpm.



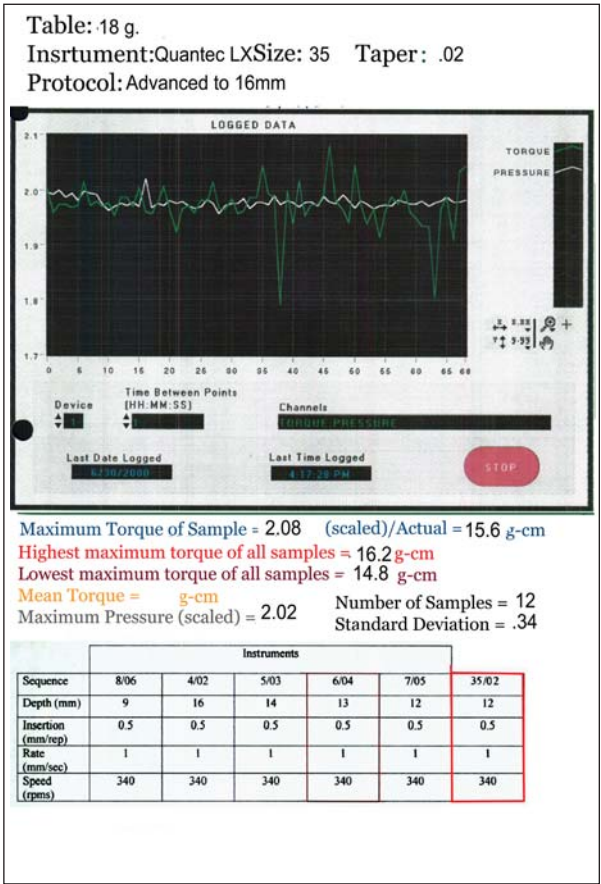
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Group 8 continued. In a Crown-down sequence, each **Quantec** file preceded or followed another Quantec file in a series and advanced into a simulated canal in a plastic block at a rate of 1mm/s with 1mm insertion increments to a designated depth. at rotation speed of 340rpm.



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Group 8 continued. In a Crown-down sequence, each **Quantec** file preceded or followed another Quantec file in a series and advanced into a simulated canal in a plastic block at a rate of 1mm/s with 1mm insertion increments to a designated depth. at rotation speed of 340rpm.



Note that the 25-.02 **Quantec LX** file was used in Table 18 e. and the Quantec SC file was used in Table f. The SC(safe-cutting) file resulted in significantly less torsion stress. The selection of the SC tip design may be a consideration in an abrupt apical curvature where stress of distortion may be substantial and the amount of total stress is a concern. Refer to instrumentation consideration number 1 on page 105:

Select the tip design that will not burnish or transport the canal.

Note that enlargement with the 35-.02 Quantec LX file used in Table 18 g. resulted in minimum torsion stress when carried to the same depth as the 25-.02 files. Preceding its use with coronal flaring reduced coronal stress.

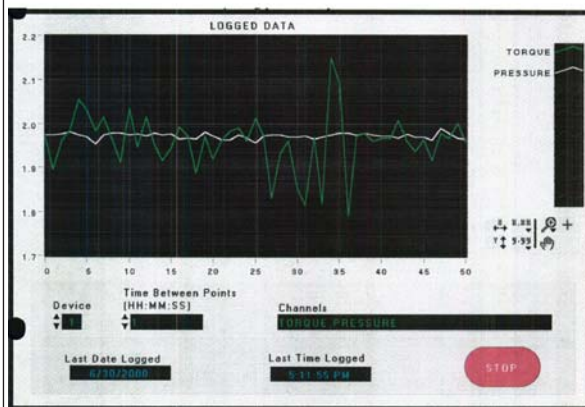
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Group 9. In a Step-back sequence, after coronal enlargement with a 25-.06 **Quantec** file, each Quantec file is followed by another Quantec file with a greater taper in a series and advanced into a simulated canal in a plastic block at a rate of 1mm/s with 1mm insertion increments to a designated depth. at rotation speed of 340rpm.

Table: 19 a. (111)

Insrtument:Quantec LXSize: 25 Taper: .06

Protocol: Step-back sequence. 1st file as orifice opener.



Maximum Torque of Sample =2.15 (scaled)/Actual = 22.1 g-cm

Highest maximum torque of all samples = 21.6 g-cm

Lowest maximum torque of all samples = 15.4 g-cm

Mean Torque = g-cm

Number of Samples = 12

Maximum Pressure (scaled) = 1.99

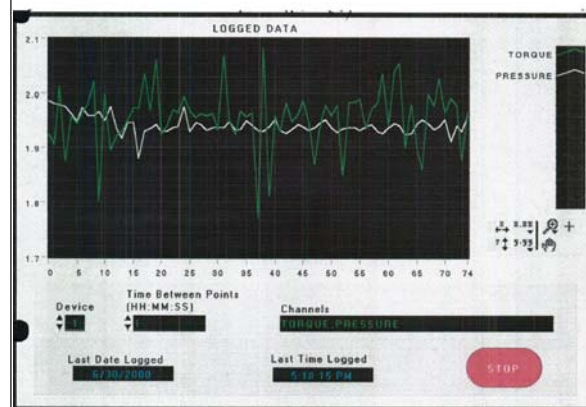
Standard Deviation = 3.2

Sequence	Instruments				
	8/06	4/02	5/03	6/04	7/05
Depth (mm)	9	16	14	13	12
Insertion (mm/rep)	0.5	0.5	0.5	0.5	0.5
Rate (mm/sec)	1	1	1	1	1
Speed (rpm)	340	340	340	340	340

Table: 19 b.

Insrtument:Quantec SCSize: 25 Taper: .02

Protocol: Step-back sequence. Safe cutting tip as 1st to WL



Maximum Torque of Sample =2.07 (scaled)/Actual = 10.4 g-cm

Highest maximum torque of all samples = 12.1 g-cm

Lowest maximum torque of all samples = 9.9 g-cm

Mean Torque = g-cm

Number of Samples = 12

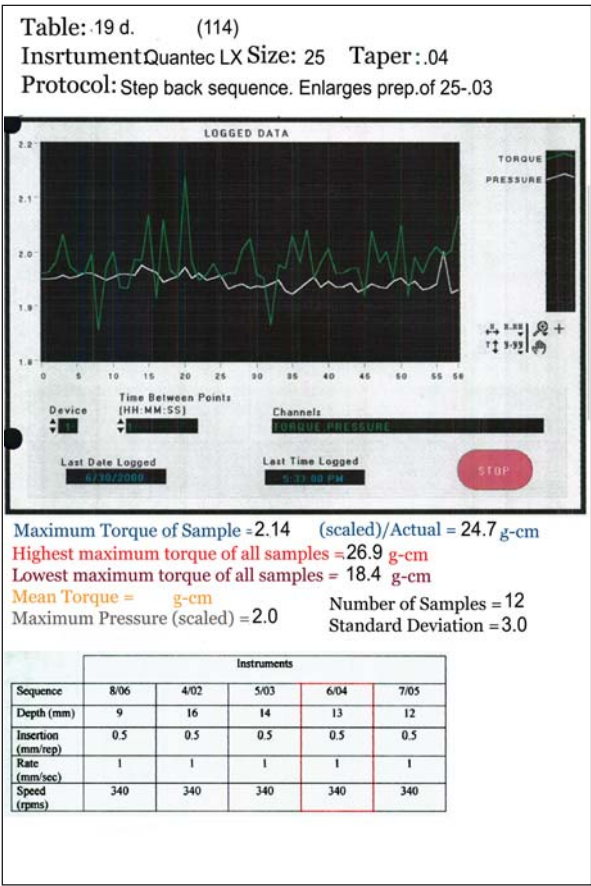
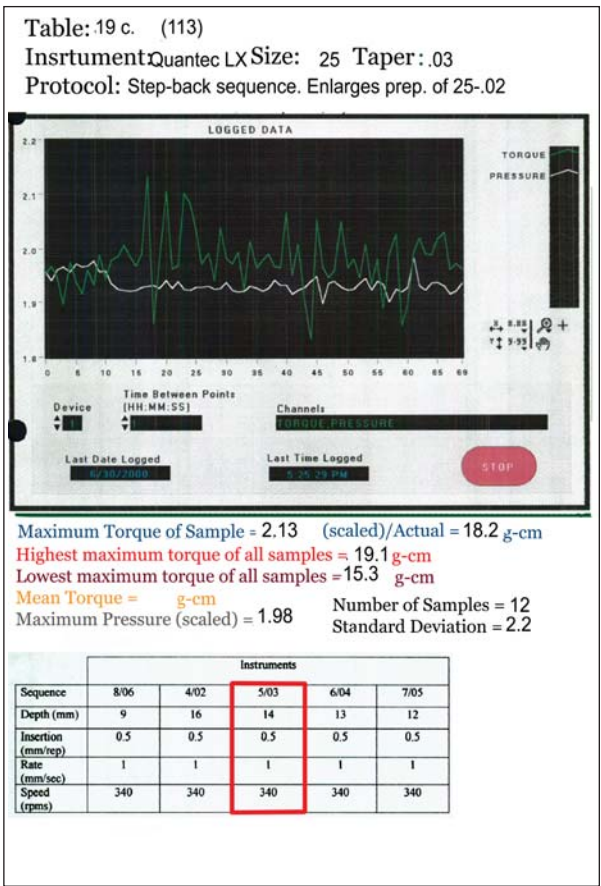
Maximum Pressure (scaled) = 1.98

Standard Deviation = 1.2

Sequence	SC Instruments				
	8/06	4/02	5/03	6/04	7/05
Depth (mm)	9	16	14	13	12
Insertion (mm/rep)	0.5	0.5	0.5	0.5	0.5
Rate (mm/sec)	1	1	1	1	1
Speed (rpm)	340	340	340	340	340

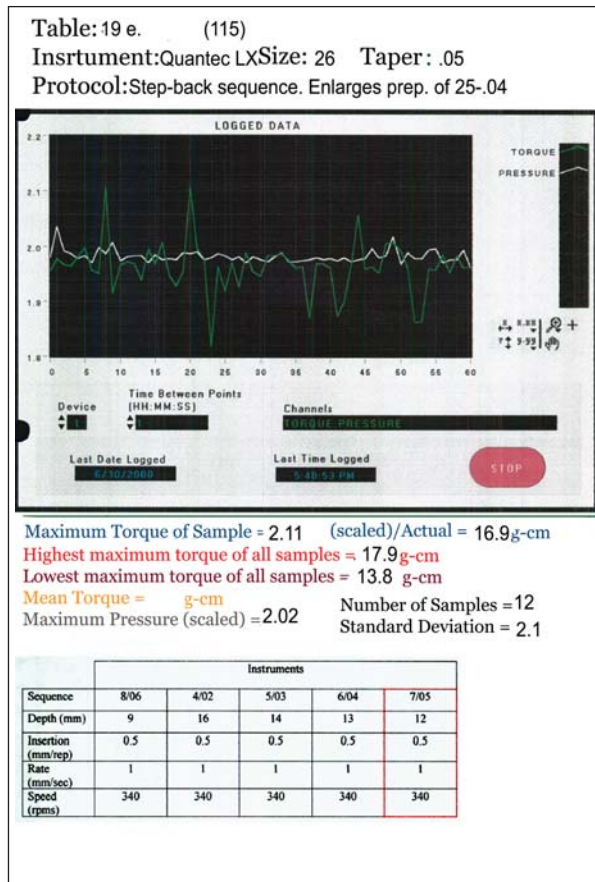
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Group 9 continued. In a Step-back sequence, after coronal enlargement with a 25-.06 Quantec file, each Quantec file is followed by another Quantec file with a greater taper in a series and advanced into a simulated canal in a plastic block at a rate of 1mm/s with 1mm insertion increments to a designated depth. at rotation speed of 340rpm.



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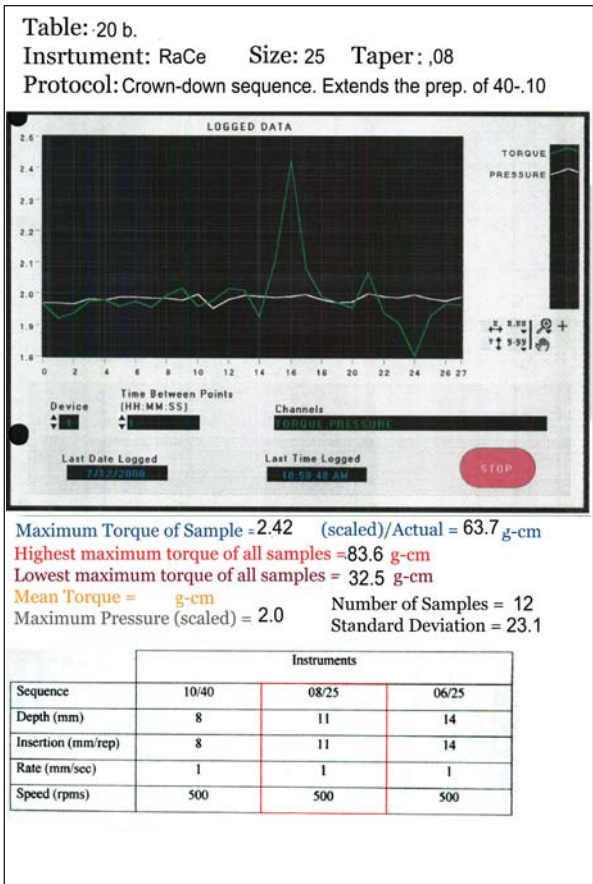
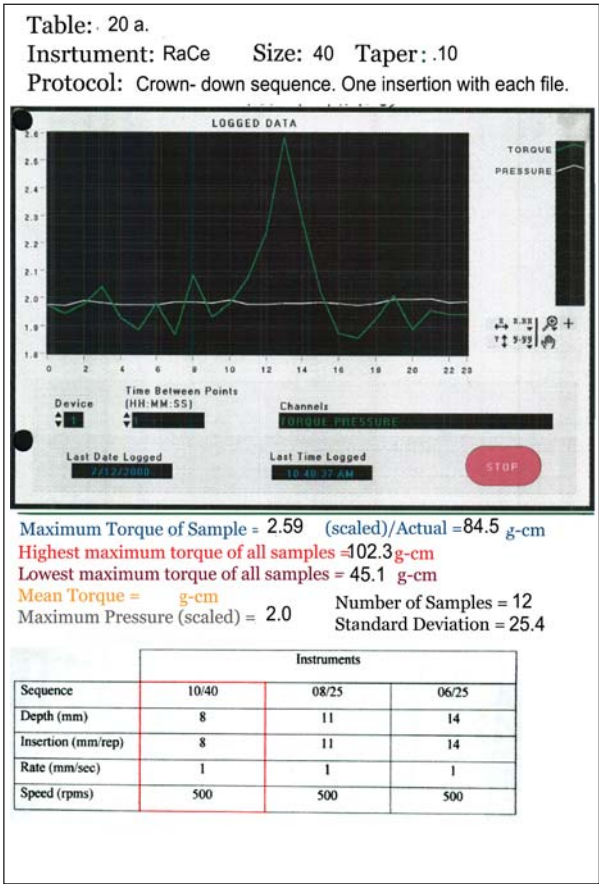
Group 9 continued. In a Step-back sequence, after coronal enlargement with a 25-.06 Quantec file, each Quantec file is followed by another Quantec file with a greater taper in a series and advanced into a simulated canal in a plastic block at a rate of 1mm/s with 1mm insertion increments to a designated depth. at rotation speed of 340rpm.



Compare the torsion stress of the files in Group 8 with the files in Group 9. Note that there is no significances difference in the torsion stress in the crown-down or the step-back sequence, yet the most popular recommended approach is the Crown-down technique. Keep in mind that most of the stress is on the tip portion of the file, its most vulnerable segment, during a crown-down approach and the greatest stress is on the handle portion during a step-back approach.

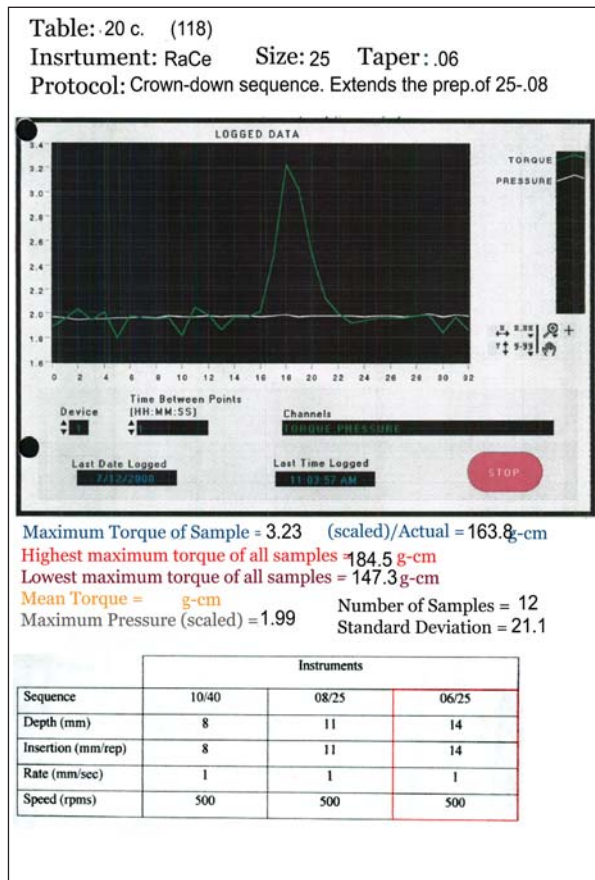
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Group 10. In a Crown-down sequence, each **RaCe** file preceded or followed another RaCe file in a series and advanced into a simulated canal in a plastic block at a rate of 1mm/s with one continuous insertion to a designated depth. at rotation speed of 500rpm.



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Group 10 continued. In a Crown-down sequence, each **RaCe** file preceded or followed another RaCe file in a series and advanced into a simulated canal in a plastic block at a rate of 1mm/s with one continuous insertion to a designated depth. at rotation speed of 500rpm.



Note that there was no significance difference between the 25-.08 and 25-.06 of Group 10 and the 20-.08 and 20-.06 of Group 4 of Profile GT except for the speed of rotation.

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Group 11. In a Crown-down sequence, each RaCe file preceded or followed another RaCe file in a series and advanced into a simulated canal in a plastic block at a rate of 1mm/s with 0.5 mm insertion advancements to a designated depth. at rotation speed of 500rpm.

Table: 21 a. (122)
 Insrtument: RaCe Size: 40 Taper: .10
 Protocol: Crown-down sequence. 1st file using short insertions



Maximum Torque of Sample = 2.28 (scaled)/Actual = 41.6 g-cm
 Highest maximum torque of all samples = 93.1 g-cm
 Lowest maximum torque of all samples = 26.4 g-cm
 Mean Torque = g-cm
 Maximum Pressure (scaled) = 1.98 Number of Samples = 12
 Standard Deviation = 33.7

	Instruments			
Sequence	10/40	08/25	06/25	35/02
Depth(mm)	8	11	14	14
Insertion (mm/rep)	0.5	0.5	0.5	0.5
Rate(mm/sec)	1	1	1	1
Speed (rpms)	500	500	500	500

Table: 21 b.
 Insrtument: RaCe Size: 25 Taper: .08
 Protocol: Crown-down sequence. Extends prep. of 40-.10

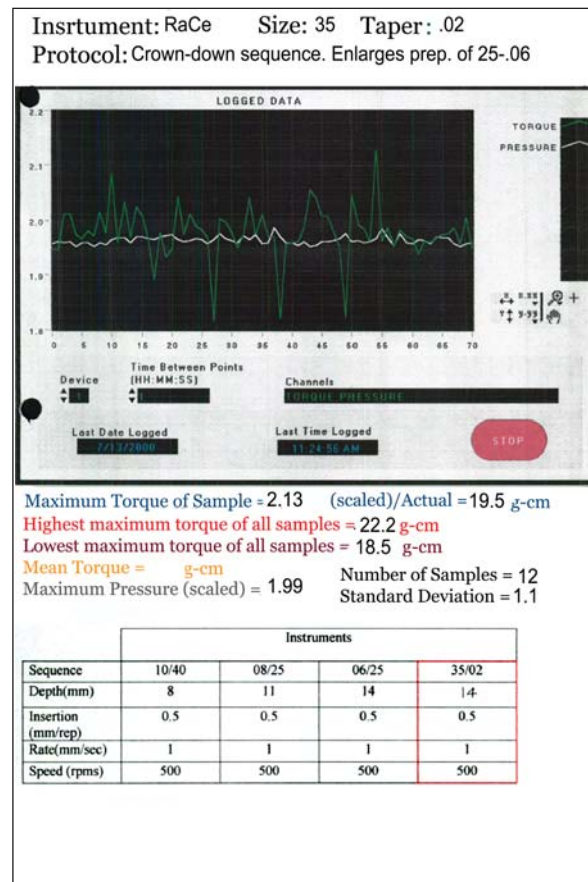
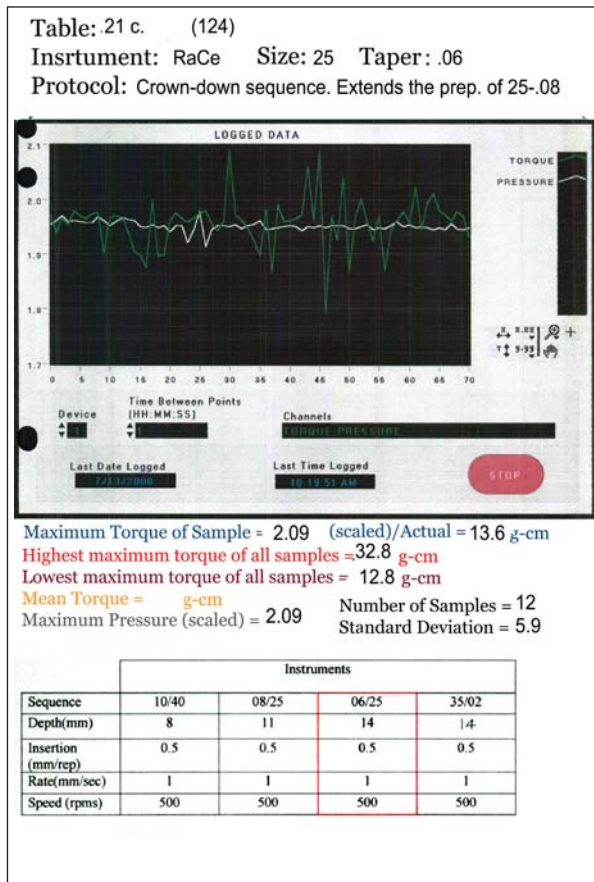


Maximum Torque of Sample = 2.12 (scaled)/Actual = 20.8 g-cm
 Highest maximum torque of all samples = 36.9 g-cm
 Lowest maximum torque of all samples = 19.1 g-cm
 Mean Torque = g-cm
 Maximum Pressure (scaled) = 1.98 Number of Samples = 12
 Standard Deviation = 7.2

	Instruments			
Sequence	10/40	08/25	06/25	35/02
Depth(mm)	8	11	14	14
Insertion (mm/rep)	0.5	0.5	0.5	0.5
Rate(mm/sec)	1	1	1	1
Speed (rpms)	500	500	500	500

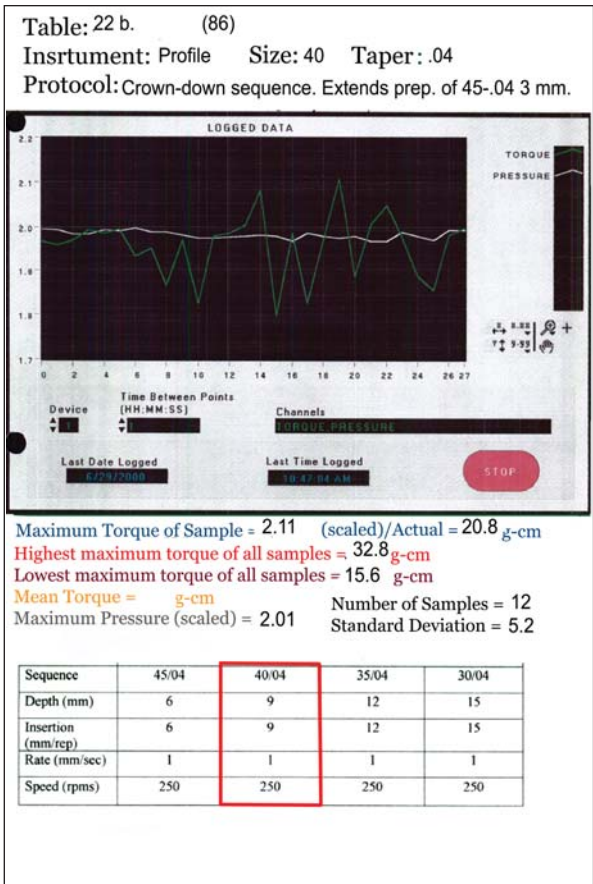
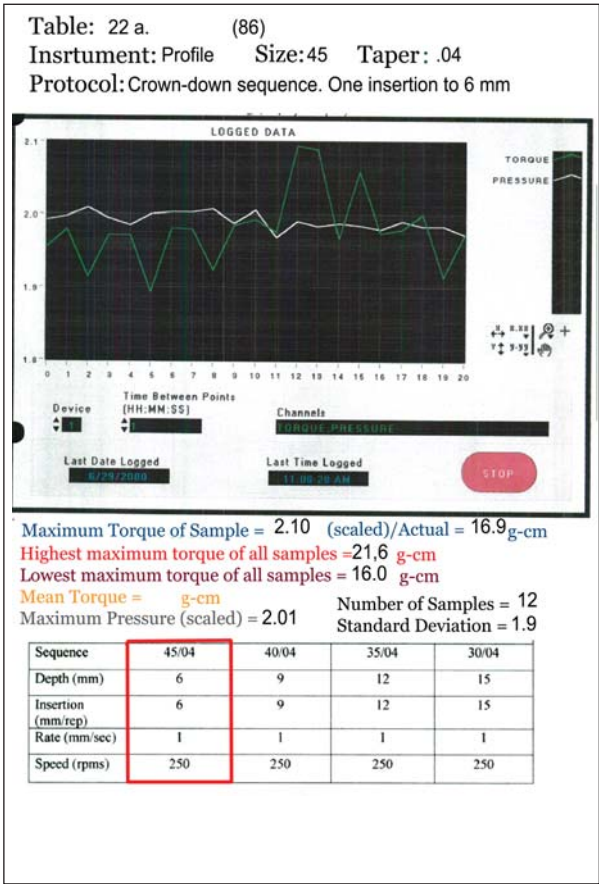
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Group 11 continued. In a Crown-down sequence, each RaCe file preceded or followed another RaCe file in a series and advanced into a simulated canal in a plastic block at a rate of 1mm/s with 0.5 mm insertion advancements to a designated depth. at rotation speed of 500rpm. (Note that the 0.5 advancements of Group 11 significantly reduced the torsion stress that resulted in Group 10.)



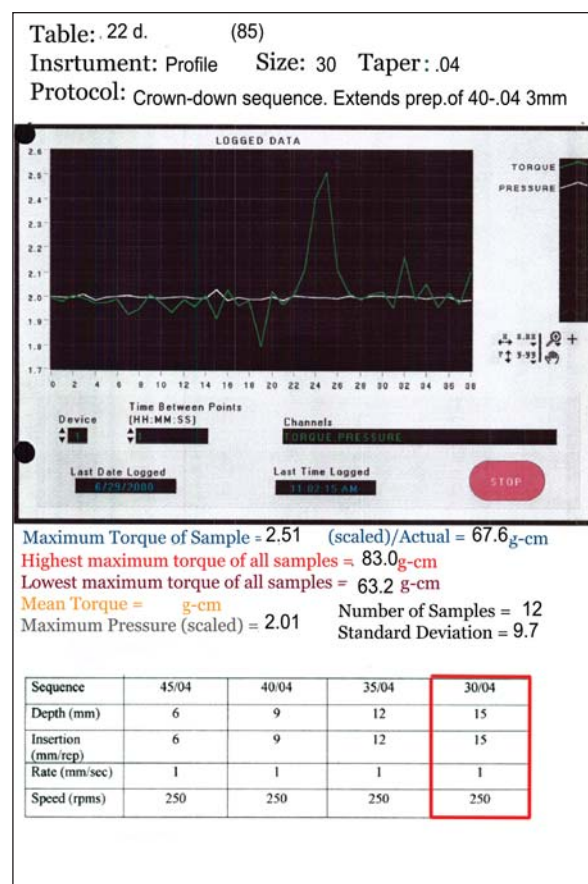
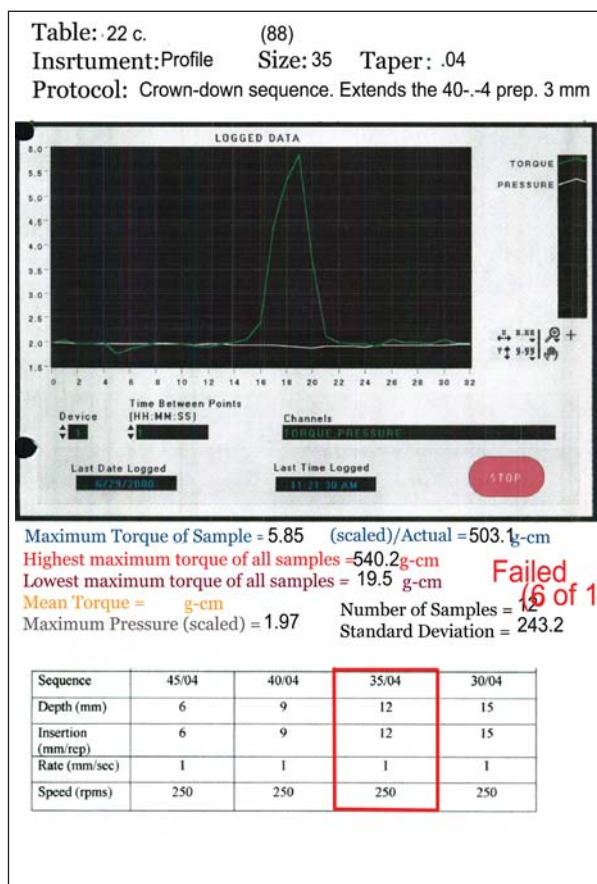
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Group 12. In a Crown-down sequence, each **Profile** file preceded or followed another Profile file in a series and advanced into a simulated canal in a plastic block at a rate of 1mm/s with 1 continuous insertion to a designated depth. at rotation speed of 300rpm.



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Group 12 continued. In a Crown-down sequence, each **Profile** file preceded or followed another Profile file in a series and advanced into a simulated canal in a plastic block at a rate of 1mm/s with 1 continuous insertion to a designated depth. at rotation speed of 300rpm.



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Note: Group 12 and Group 7 follow the same sequence in a crown-down approach for instrumentation except the Group 12 advances the 40-.04, 35-.04 and 30-.04 files 3mm with insertion advancements instead of the 2mm insertion advancements of the Group 7. Only a 2mm shorter depth in insertion of the 35-.04 file of Group 7 reduced the number of failures by one half. Nevertheless, any risk for failure should be minimized. A more effective reduction of risks was accomplished by replacing the one continuous insertion with 0.5mm insertion advancements. Refer to instrumentation considerations on page 105:

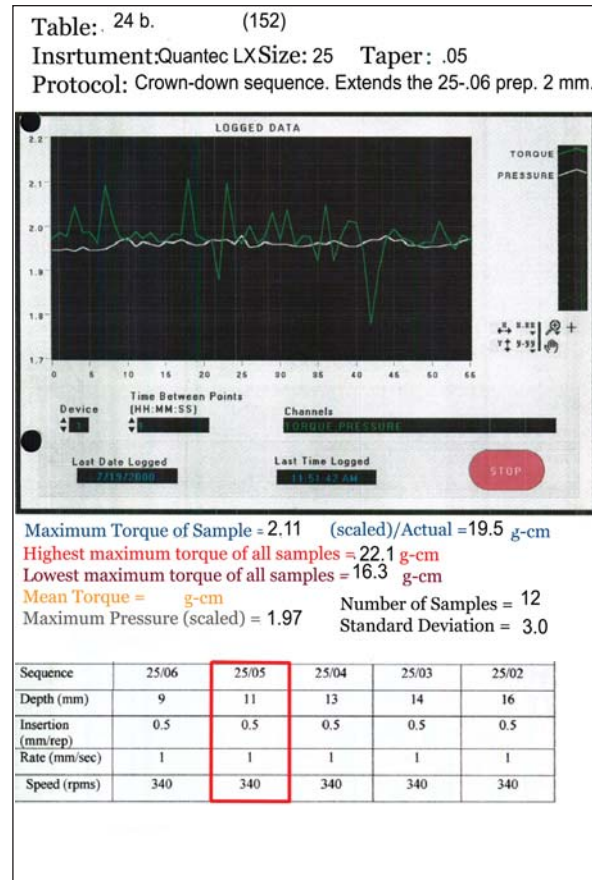
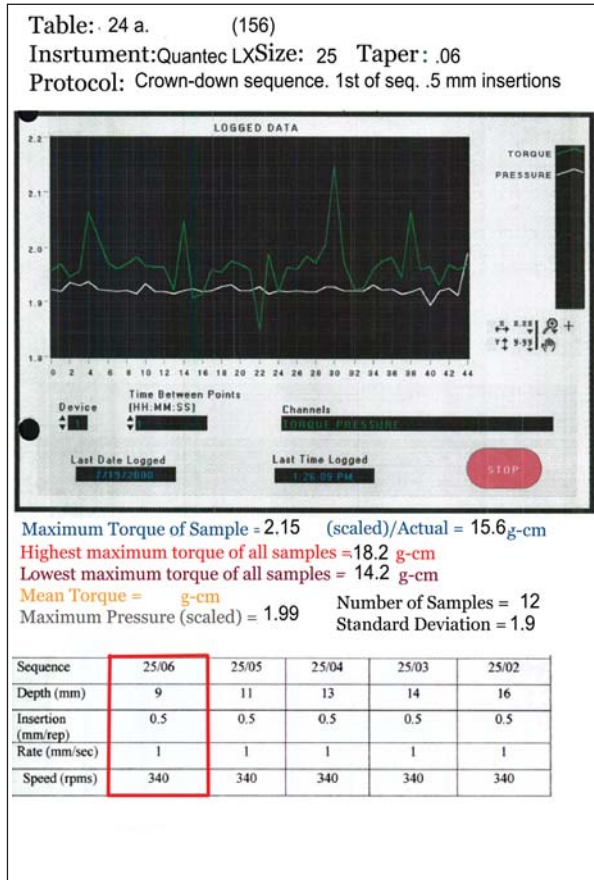
2. Advance the file into the canal with no more than 1mm increments with insert/withdraw motions.

5. If a file has more than a .02 taper, do not advance more than 2mm beyond the preparation of the previous file if any part of the file is engaged in a curvature. 6. Except for .02 tapered files having a file diameter of .20mm and smaller, do not engage more than 6mm of the file's working surface if the file is engaged in a curvature.

Note that the 30-.04 files of Group 7 and Group 12 exhibited an acceptable torsion stress level while the 35-.04 files did not even though the 30-.04 files of both groups were inserted to a greater depth. This points out the importance of diameters while considering file engagement especially when even a small tip portion of the file is engaged in a curvature.

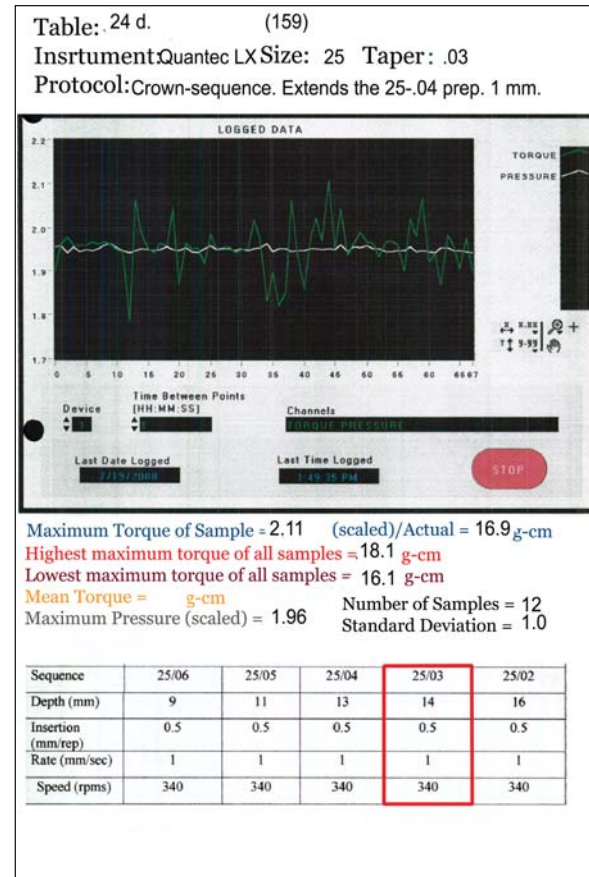
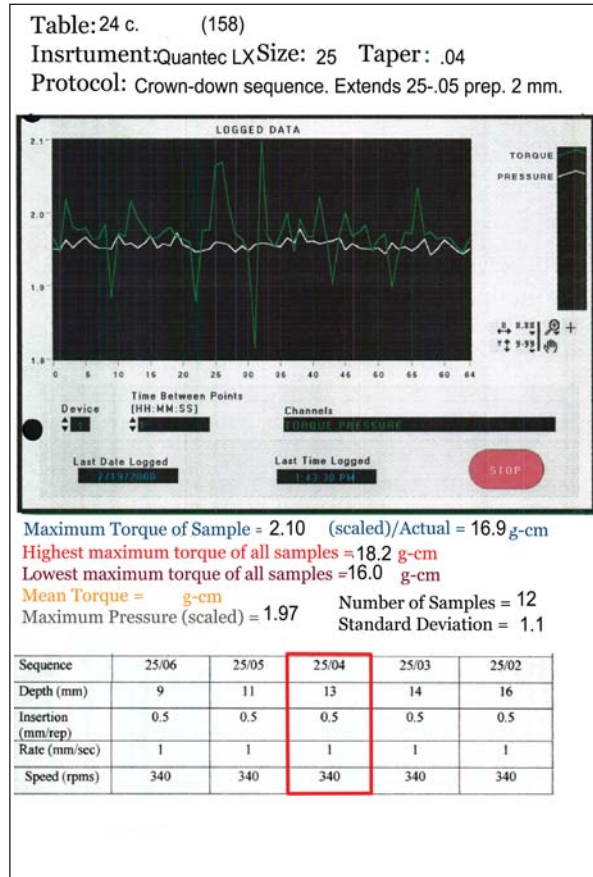
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Group 13. In a Crown-down sequence, each **Quantec** file preceded or followed another Quantec file in a series and advanced into a simulated canal in a plastic block at a rate of 1mm/s with 0.5mm insertion increments to a designated depth. at rotation speed of 340rpm.



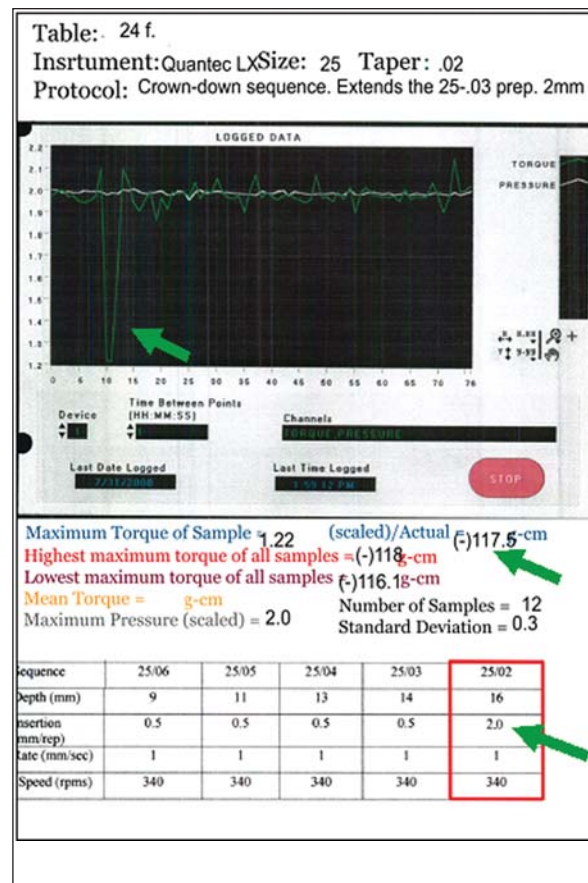
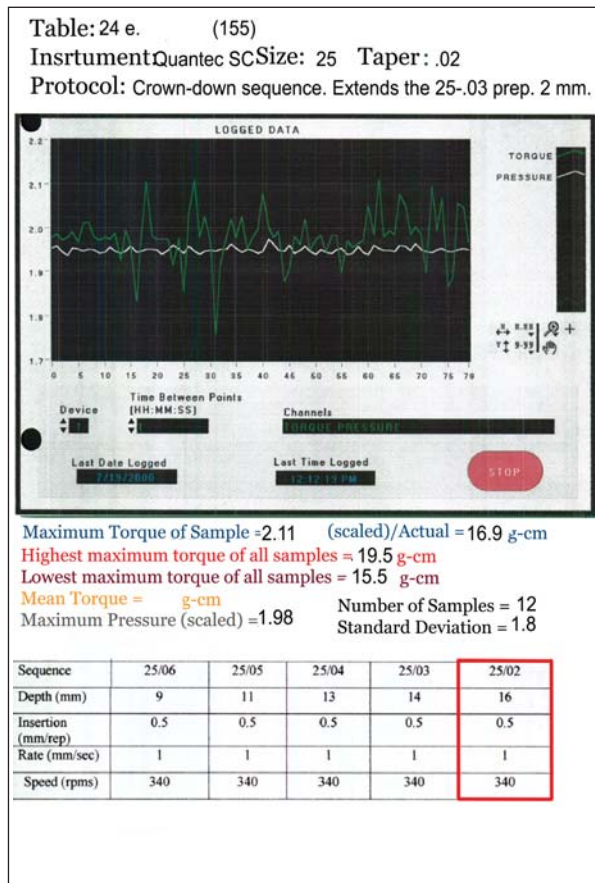
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Group 13 continued. In a Crown-down sequence, each **Quantec** file preceded or followed another Quantec file in a series and advanced into a simulated canal in a plastic block at a rate of 1mm/s with 0.5mm insertion increments to a designated depth. at rotation speed of 340rpm.



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Group 13 continued. In a Crown-down sequence, each **Quantec** file preceded or followed another Quantec file in a series and advanced into a simulated canal in a plastic block at a rate of 1mm/s with 0.5mm insertion increments to a designated depth. at rotation speed of 340rpm.



Note that the parameters of Group 13 and Group 8 are the same except the files of Group 8 were advanced in 1mm increments and those in Group 13 were advanced in .05mm increments. The exception was for the files of Table 24 f.

There was no significant difference between files that advanced in 1mm and 0.5 increments. However, the files of 24 f. which were advanced in 2mm increments had a tendency

to screw-in and result in negative torsion. The stress was not excessive but a negative torsion can be as stressful as a positive one. Refer to considerations for instrumentation on page 105:

2. Advance a file into a canal with no more than increments with insert/withdraw motions.

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Group 14. In a Crown-down sequence, each **Profile GT** file preceded or followed another Profile GT file in a series and advanced into a simulated canal in a plastic block at a rate of 1mm/s with 1 continuous insertion to a designated depth. at rotation speed of 340rpm.

Table: 25 a. (161)
Insrtument: Profile GT Size: 20 Taper: .10
Protocol: Crown-down sequence. 1st of seq. To 8 mm with 1 insertio



Maximum Torque of Sample = 2.11 (scaled)/Actual = 18.2 g-cm
Highest maximum torque of all samples = 18.4 g-cm
Lowest maximum torque of all samples = 14.3 g-cm
Mean Torque = g-cm
Maximum Pressure (scaled) = 1.99
Number of Samples = 12
Standard Deviation = 1.9

Sequence	20/10	20/08	20/06
Depth (mm.)	8	11	14
Insertion (mm/rep)	8	11	14
Rate (mm/sec)	1	1	1
Speed (rpms)	340	340	340

Table: 25 b.
Insrtument: Profile GT Size: 20 Taper: .08
Protocol: Crown-down sequence. Extended 20-.10 prep. 3mm



Maximum Torque of Sample = 4.57 (scaled)/Actual = 336.7 g-cm
Highest maximum torque of all samples = 492.1 g-cm
Lowest maximum torque of all samples = 48.8 g-cm
Mean Torque = g-cm
Maximum Pressure (scaled) = 1.98
Number of Samples = 12
Standard Deviation = 225.6

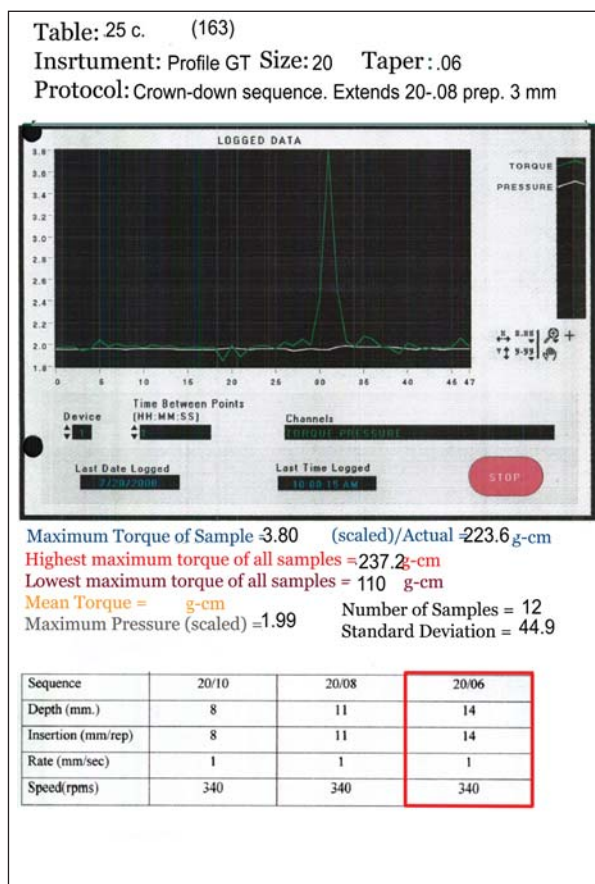
Sequence	20/10	20/08	20/06
Depth (mm.)	8	11	14
Insertion (mm/rep)	8	11	14
Rate (mm/sec)	1	1	1
Speed (rpms)	340	340	340

(2 of 12 failed)

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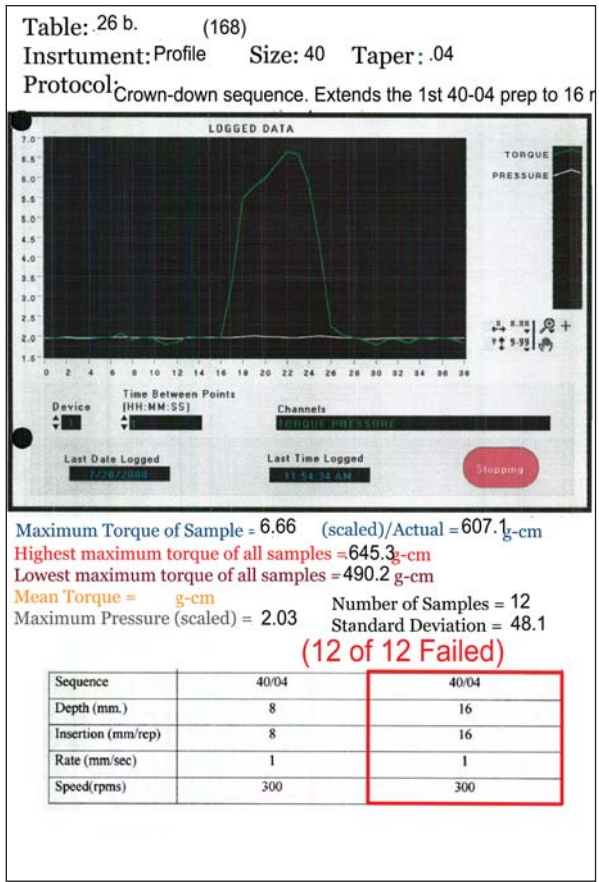
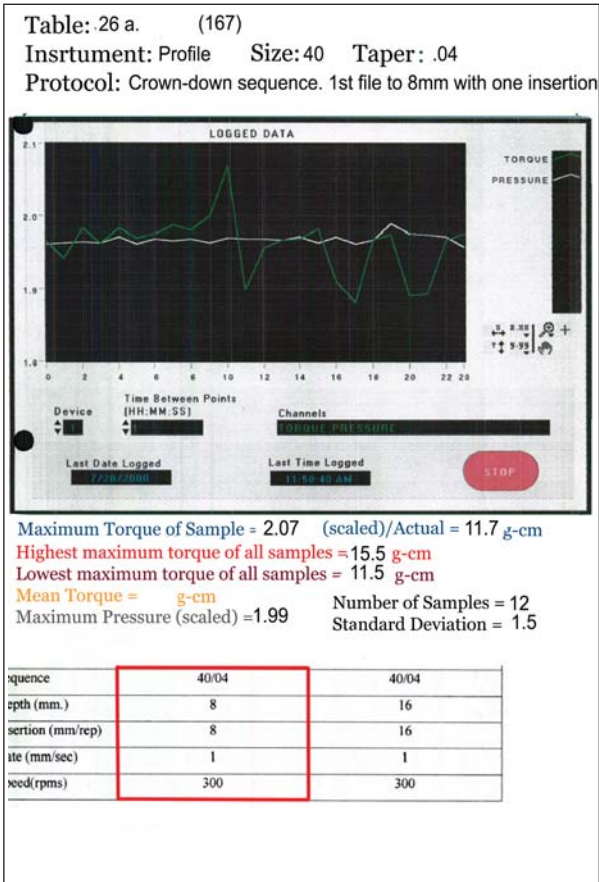
Group 14 continued. In a Crown-down sequence, each **Profile GT** file preceded or followed another Profile GT file in a series and advanced into a simulated canal in a plastic block at a rate of 1mm/s with 1 continuous insertion to a designated depth. at rotation speed of 340rpm.



Note that the parameters of Group 14 and Group 6 are the same except for the speed of rotation. Rotations for files of Group 6 are 300rpm, whereas the rotation speeds of Group 14 are 340rpm. Increasing the speed of rotation significantly reduced the stress of torsion for each file size.

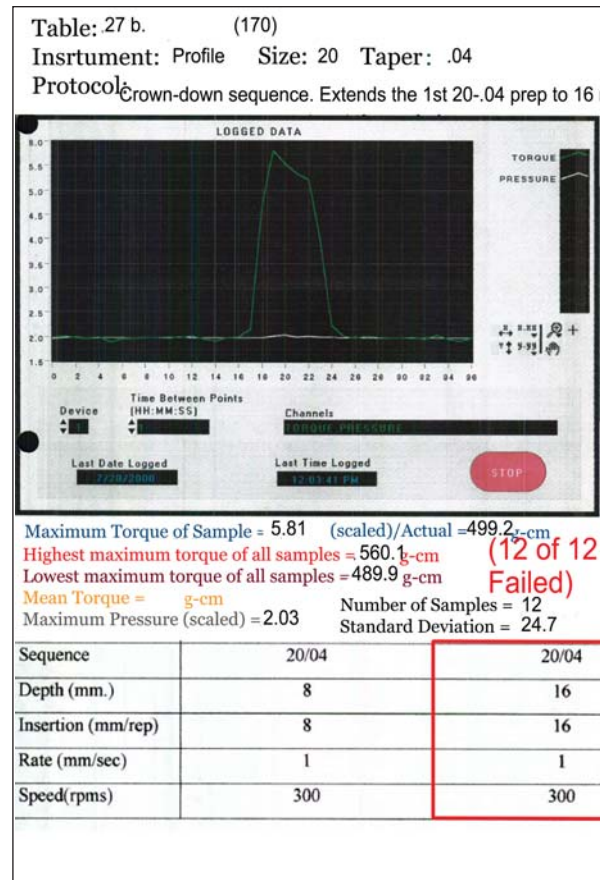
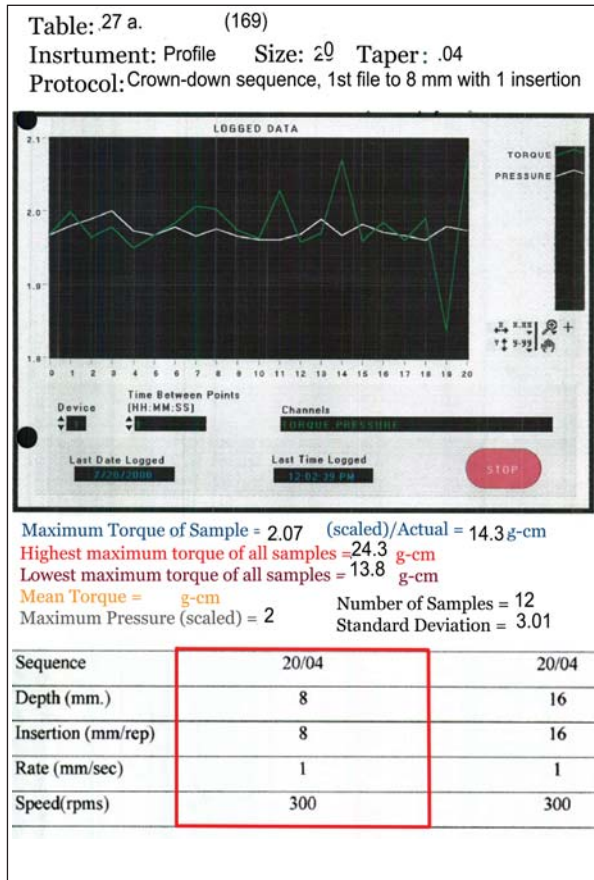
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Group 15. Profile GT files were advanced 8mm into a simulated canal in a plastic block at a rate of 1mm/s with 1 continuous insertion at rotation speed of 340rpm. The canal was then extended by advancing a new file of the same dimensions an additional 8mm.



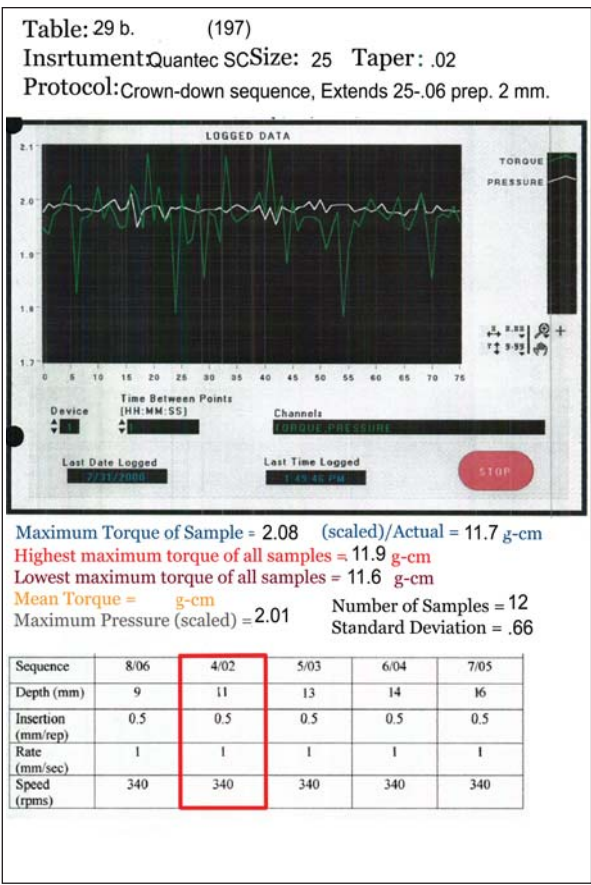
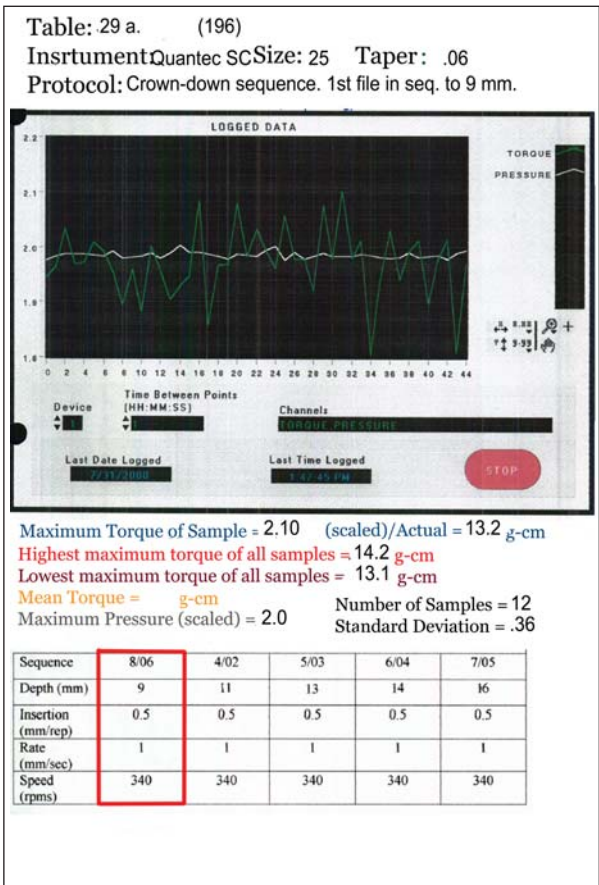
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Group 15 continued. Profile GT files were advanced 8mm into a simulated canal in a plastic block at a rate of 1mm/s with 1 continuous insertion at rotation speed of 340rpm. The canal was then extended by advancing a new file of the same dimensions an additional 8mm. (Note that removing debris and unloading the stress on the file did not prevent excessive stress from occurring when the file became fully engaged with its working surface under these circumstances.)



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Group 16. After enlarging the coronal portion of the canal with a **Quantec SC 25-.06** to a depth of 9mm, each file extended the depth of the canal as the tapers became progressively larger in a simulated canal in a plastic block at a rate of 1mm/s with 0.5mm insertion increments to a designated depth at rotation speed of 340rpm.



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Group 16 continued. After enlarging the coronal portion of the canal with a **Quantec SC 25-.06**, each file extended the depth of the canal as the tapers became progressively larger in a simulated canal in a plastic block at a rate of 1mm/s with 0.5mm insertion increments to a designated depth at rotation speed of 340rpm.

Table:29 c. (198)
Instrument:Quantec LXSize: 25 Taper: .03
Protocol: Crown-down sequence. Extends the 25-.02 prep 2 mm



Maximum Torque of Sample = 2.17 (scaled)/Actual = 31.2 g-cm
Highest maximum torque of all samples = 35.7 g-cm
Lowest maximum torque of all samples = 21.1 g-cm
Mean Torque = g-cm
Maximum Pressure (scaled) = 2.0 Number of Samples = 12
Standard Deviation = 5.5

Sequence	8/06	4/02	5/03	6/04	7/05
Depth (mm)	9	11	13	14	16
Insertion (mm/rep)	0.5	0.5	0.5	0.5	0.5
Rate (mm/sec)	1	1	1	1	1
Speed (rpm)	340	340	340	340	340

Table: 29 d. (214)
Instrument:Quantec LXSize: 25 Taper: .04
Protocol: Crown-down sequence, Extends the 25-.03 prep. 1 mm.

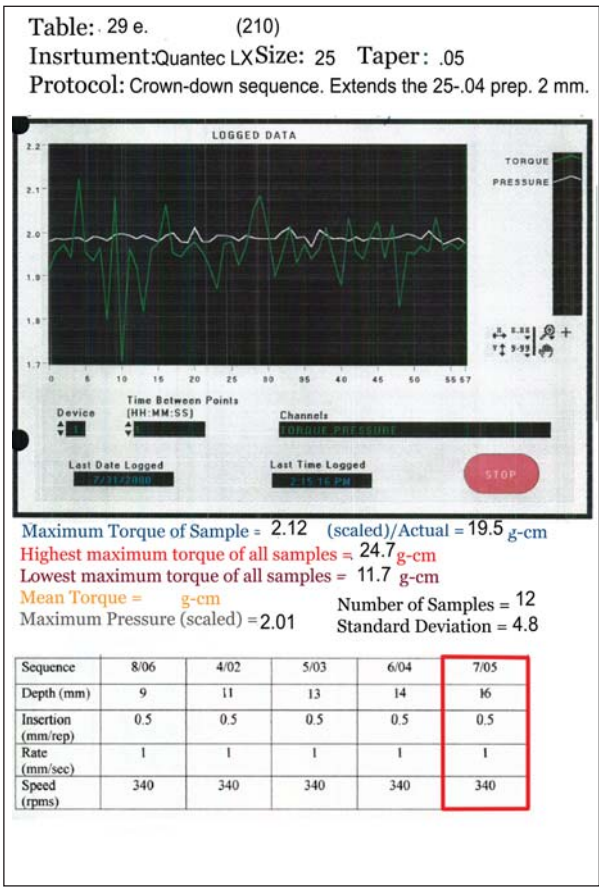


Maximum Torque of Sample = 2.10 (scaled)/Actual = 18.2 g-cm
Highest maximum torque of all samples = 18.2 g-cm
Lowest maximum torque of all samples = 11.7 g-cm
Mean Torque = g-cm
Maximum Pressure (scaled) = 1.97 Number of Samples = 12
Standard Deviation = 2.9

Sequence	8/06	4/02	5/03	6/04	7/05
Depth (mm)	9	11	13	14	16
Insertion (mm/rep)	0.5	0.5	0.5	0.5	0.5
Rate (mm/sec)	1	1	1	1	1
Speed (rpm)	340	340	340	340	340

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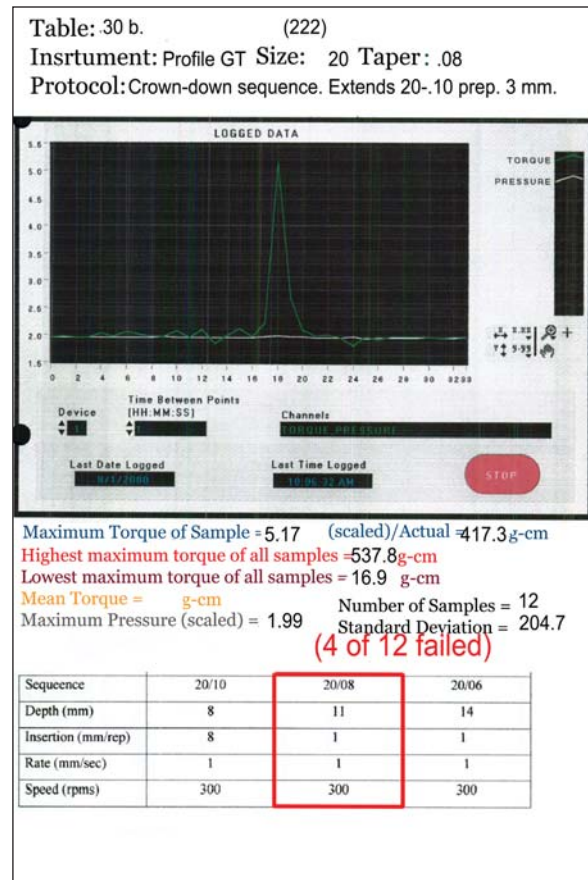
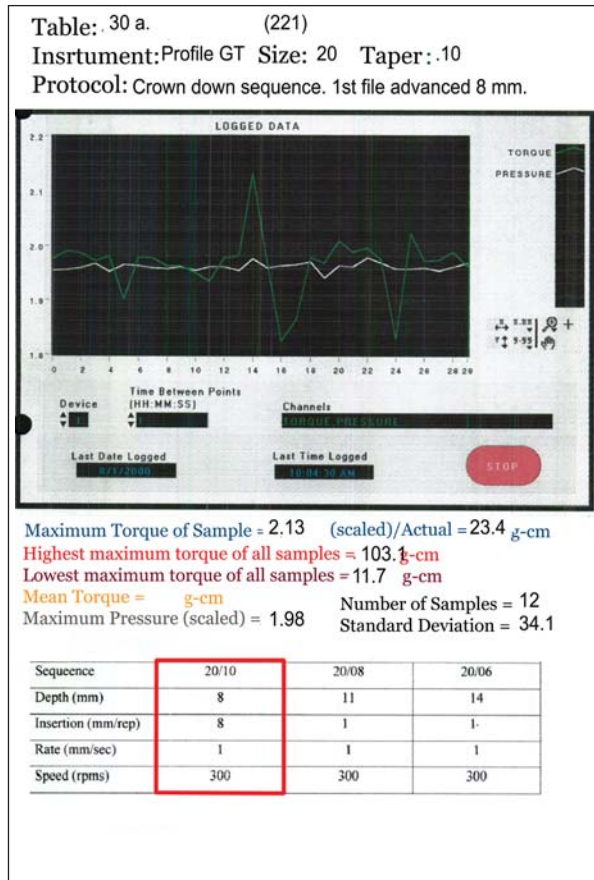
Group 16 continued. After enlarging the coronal portion of the canal with a **Quantec SC 25-.06**, each file extended the depth of the canal as the tapers became progressively larger in a simulated canal in a plastic block at a rate of 1mm/s with 0.5mm insertion increments to a designated depth at rotation speed of 340rpm.



Note that the torsion stress for each file was not significantly different from the values obtained in Group 8 or Group 13. Even though this sequence may seem counter-intuitive and the sequence is not one to be selected as having the least risk, the results exhibited relatively low torsion stress. These results are probably due to the short insertion repetitions and the short advancement depths.

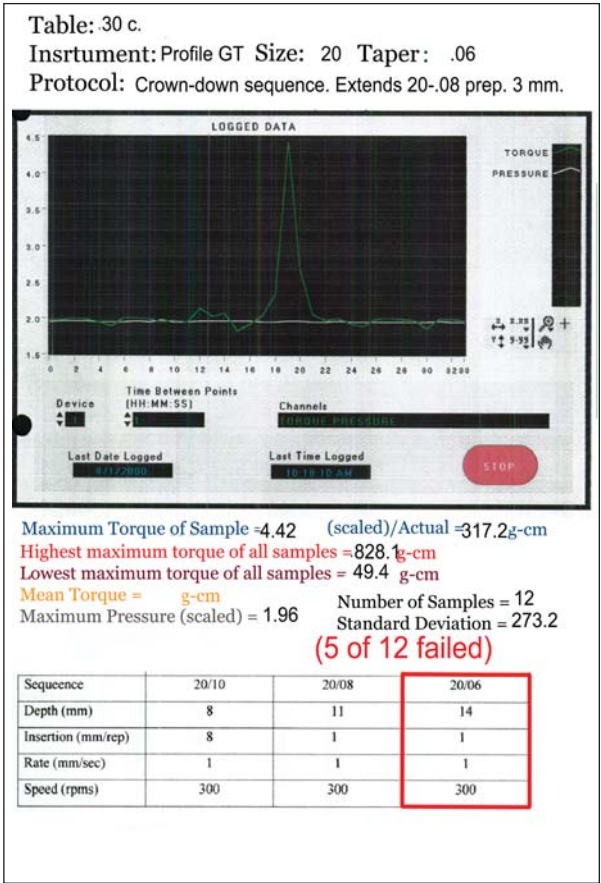
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Group 17. In a Crown-down sequence, each **Profile GT** file preceded or followed another Profile GT file in a series and advanced into a simulated canal in a plastic block at a rate of 1mm/s with 1 mm advancements to a designated depth. at rotation speed of 300rpm.



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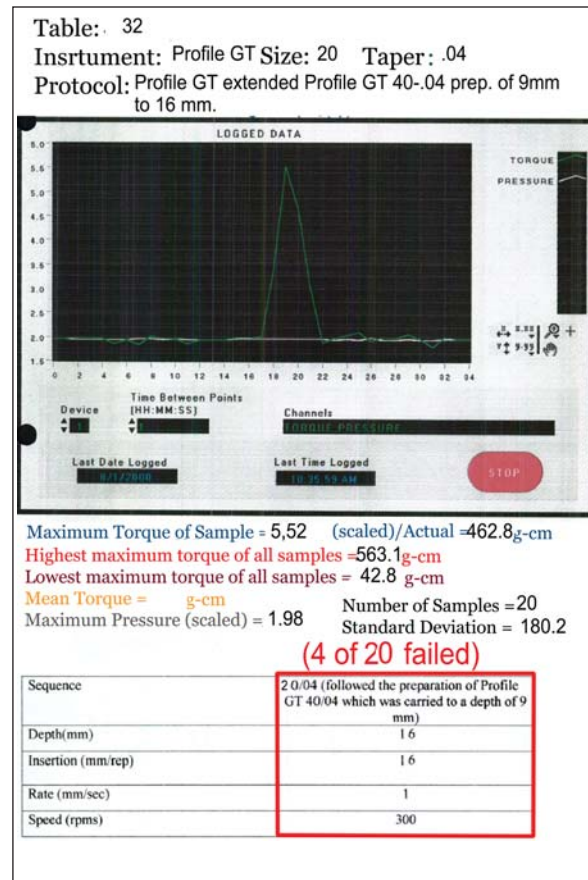
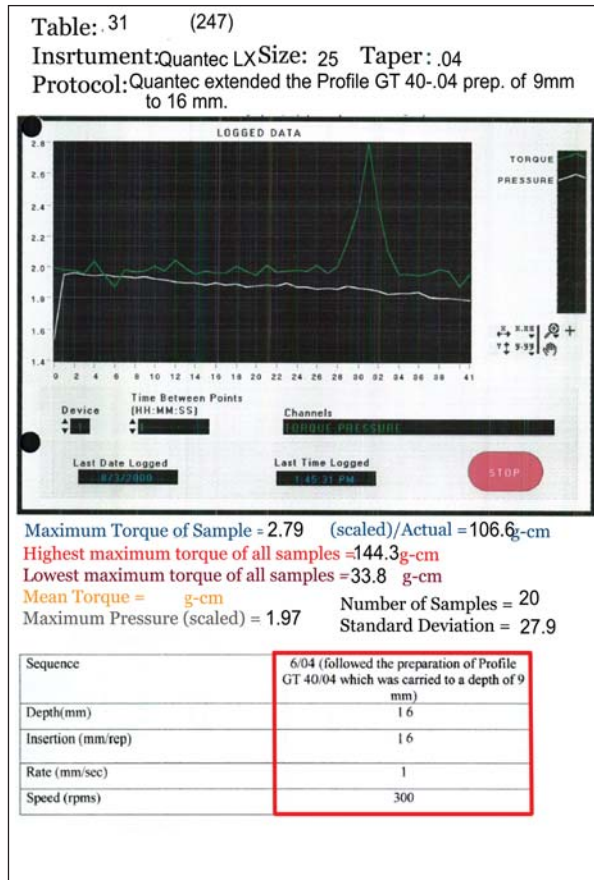
Group 17 continued. In a Crown-down sequence, each **Profile GT** file preceded or followed another Profile GT file in a series and advanced into a simulated canal in a plastic block at a rate of 1mm/s with 1 mm advancements to a designated depth. at rotation speed of 300rpm.

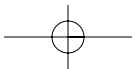
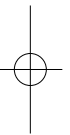
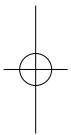
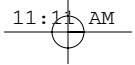


Note the results Group 17 compared to those of Group 6 and those of Group 14. The files in Group 14 were inserted with 1 continuous motion but only for a 3mm extension of the preparation and at a rotation speed of 340rpm. The failure rates for Group 17 were higher even though the files were advanced in 1mm increments. The 340rpm rotation speed was more advantageous over the 300rpm rotation speed under these particular circumstances.

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Group 18. Each file extended the preparation of a 40-.04 file enlargement with a depth of 9mm in a simulated canal in a plastic block and advanced at a rate of 1mm/s with 1 continuous insertion to a 16mm depth. at rotation speed of 300rpm.





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The DVD attached to the back cover of this book contains graphs of the results of the reasearch, illustrative video clips and a transcript of the text.

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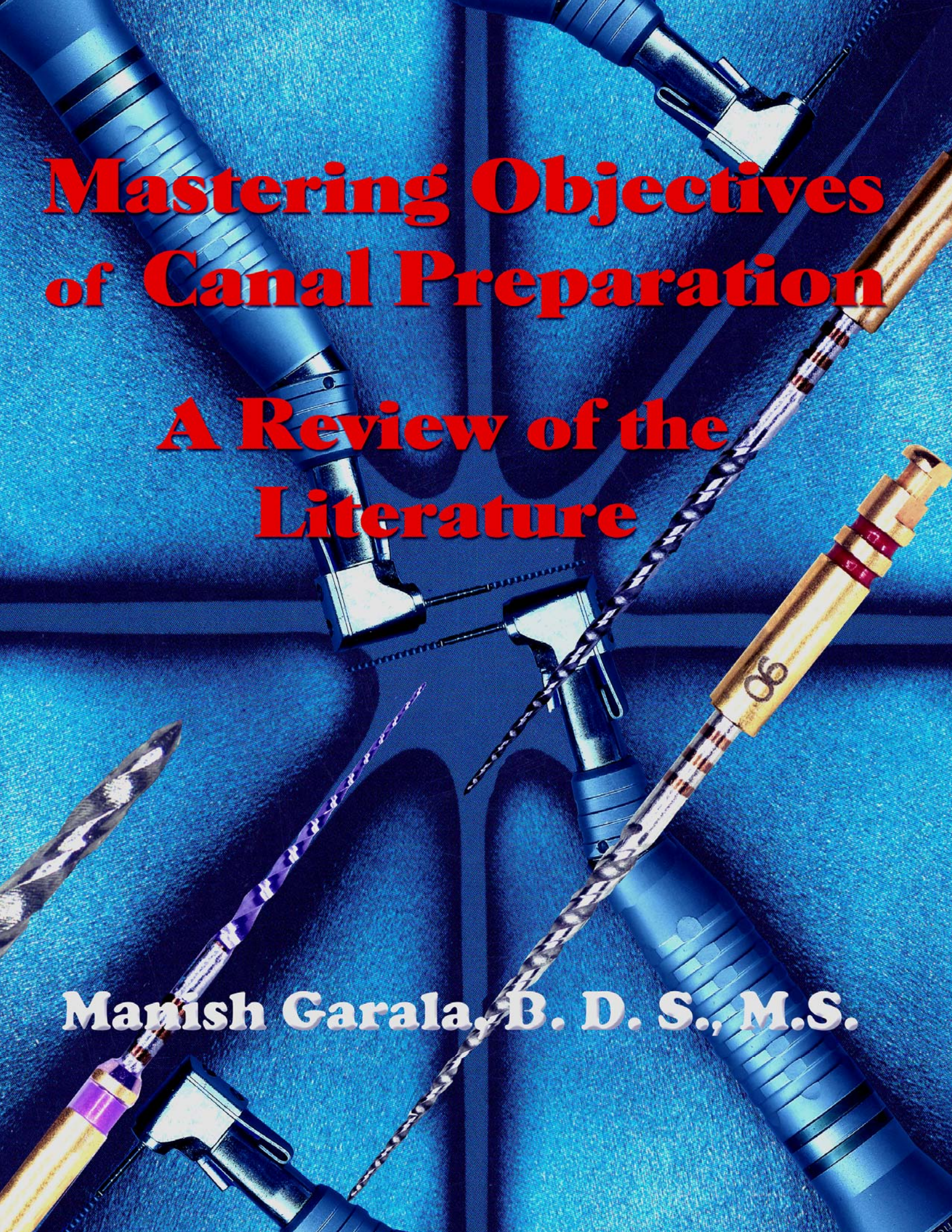
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The background of the slide is a close-up, artistic photograph of several dental handpieces and burs. The handpieces are primarily blue and silver, with some gold-colored accents. The burs are various shapes and sizes, some with blue and white markings. The lighting is dramatic, highlighting the metallic textures and creating strong shadows.

Mastering Objectives of Canal Preparation

A Review of the Literature

Manish Garala, B. D. S., M.S.

Mastering the Objectives

Dr. Manish Garala presents a thorough review of the current scientific literature examining the objectives for root canal preparation. While "Mastering Endodontic Instrumentation", by Dr. John T. McSpadden was written to help in providing the means for accomplishing canal preparation objectives, "Mastering the Objectives of Root Canal Preparation" was written to help provide the means to determine those objectives. The goal of this presentation is to offer a single source as a review of scientific findings for predictably achieving ideal root canal cleaning and shaping.

Even though a definite protocol for accomplishing all canal preparation 'objectives' might be impossible for this expansive subject, a thorough examination of the scientific research submitted is indispensable. This chapter establishes an evidence-based approach from which the clinician can formulate their techniques for advancing successful treatment.

- * Biologic objectives
- * Infections
- * Anatomical limitations
- * Apical shapes
- * Debridement
- * Irrigation
- * Influence of instruments
- * Selection of instruments
- * Instrumentation guidelines
- * Obturation objectives
- * Advances in research

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I am gratefully indebted to numerous researchers who have prioritized the importance of providing evidence-based information on root canal preparation. This information not only provides the basis for this extensive literature review but also serves to highlight the quality of endodontic research being performed worldwide. The talents these researchers possess, combined with their commitment to developing sound biologic principles, are endorsing the scientific validity of cleaning and shaping procedures. This scientific foundation also serves to advocate endodontics at a time when its clinical outcome and benefits are under scrutiny from other areas of the dental profession.

The root canal cross-sections presented in this review would not have been possible without the research team comprised of myself, Dr. Rigoberto Perez, & Dr. Sergio Kuttler from the post-graduate department of Endodontics at Nova Southeastern University. Dr. Sergio Kuttler founded the concept of the Endodontic Cube (1) in his quest for a more accurate, cost effective root sectioning technique and it has now been used to produce a number of papers examining the effects of root canal instrumentation (2, 3). His appetite for scientific knowledge on instrumentation served to highlight the deficiencies in our understanding of the most important phase of root canal therapy. I would also like to acknowledge the efforts of Dr. Stephen Schwartz for his objective review of this manuscript at short notice and his constructive criticisms.

Dr. Dudley H. Glick conceived the phrase; “We must constantly re-evaluate accepted information (scientific literature) lest we become victims of our own propaganda”. It is with these words that I introduce you to this chapter of a textbook that will unravel the uncertainties associated with endodontic instrumentation.

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INTRODUCTION

Root canal preparation remains the most challenging and critical aspect of endodontic treatment. A variety of techniques are employed by clinicians to perform each step in this multi-step process, with significant scientific and empirical debate still ongoing as to the merits of each technique used. This debate is due to the lack of a consensus on an ideal protocol for predictably successful treatment.

Rotary Nickel Titanium (Ni-Ti) instruments have revolutionized instrumentation procedures by increasing the speed and efficiency of canal preparation (Spangberg, 2001), but more importantly they have been shown to minimize canal preparation errors (Hulsmann et al. 2005). Despite the concerns pertaining to the risk of instrument breakage, their use according to guidelines and techniques presented in the volume "Mastering Canal Instrumentation" by Dr. McSpadden, should eliminate the uncertainties associated with the safety of Ni-Ti instruments.

With the significant advantages that Ni-Ti instruments demonstrate, the question presents itself as to whether the implementation of Ni-Ti instruments for canal preparation has enabled the realization of our cleaning and shaping objectives?

If our objectives are not being achieved consistently, what techniques can we incorporate in our canal preparation protocol to improve our chances for predictably achieving them?

WHY DO WE INSTRUMENT ROOT CANALS?

Globally, general dentists & endodontists perform root canal treatment daily for the purpose of tooth preservation and typically experience high success rates (Salehrabi et al. 2004).

Historically it has been confirmed that canal cleansing is the most important stage of root canal treatment (Grossman, 1943).

Canal preparation in conjunction with the use of irrigation solutions facilitates chemo-mechanical debridement for the removal of microorganisms, pulp tissue and dentinal debris from the internal canal space. It also enables removal of infected dentine from the canal wall. Preparation methods employed will significantly affect our success in canal space debridement (Barbizam et al. 2002).

WHAT DEFINITIONS EXIST ON BIOLOGIC OBJECTIVES FOR ROOT CANAL PREPARATION?

The European Society of Endodontology has defined the biologic objectives of canal preparation as the removal of remaining pulp tissue, elimination of microorganisms and removal of debris (ESE, 2006).

To more accurately define the biologic objectives of canal preparation it is essential to determine the pulpal status when treatment is initiated. This is determined by the patient's presenting symptoms, results of pulp testing, radiographic findings and clinical impressions of canal contents upon entry into the root canal (Cohen, 2002).

When it is determined that the pulp tissue is still vital, chemical and mechanical techniques are used to debride the canal space of tissue and its breakdown products which can act as stimulators for persistent periapical inflammation (Harrington et al. 1992). Bacteria are not present in the root canal system and this is irrespective of the presence of symptoms consistent with reversible or irreversible pulpitis (Dalton et al. 1998). The absence of intra-canal bacteria eliminates the need for further anti-microbial solutions or the use of a canal medicament for maximal disinfection. These additional steps are not necessary providing adequate measures are used to prevent iatrogenic bacterial contamination, mandating the use of a rubber dam, and establishing an effective inter-appointment and post-treatment coronal seal.

Disinfection becomes the ultimate objective of canal preparation once microorganisms and their byproducts become established in the root canal system. Their presence within the canal system is inevitable when there is a peri-apical radiolucency associated with a tooth, non-responsive to pulpal testing (**Sundqvist, 1976**). Undisputable evidence has existed since 1965 that bacteria are the etiology for primary pulpal & periapical infections (**Kakehashi et al. 1965**). It has also been established in numerous scientific outcome studies that the prognosis for endodontic treatment will be negatively impacted by the presence of intra-canal infections (**Sjogren et al. 1997**). For infected canals with peri-apical radiolucencies, success rates for healing are on average 13% less than for teeth demonstrating no radiolucency (**Marquis et al. 2006**).

This reduced success rate is attributed to the difficulties in disinfecting the canal system, especially when the infection has become well established. Studies using DNA-DNA hybridization techniques (**Siqueira et al. 2000**), or transmission electron microscopy (**Nair 2004**), have also identified persistent intra-canal bacteria as the principle mechanism for failure of previously performed endodontic treatment. Since specific objectives for canal preparation will differ based on the canal contents, it is logical to assume that our techniques will also need modification to achieve these objectives. This will be discussed in greater detail later in the chapter.

OBTURATION BASED OBJECTIVES OF CANAL PREPARATION

Canal shaping is also a component of canal preparation and is necessary to facilitate obturation of the canal space. The functions of this seal are to prevent the passage of microorganisms and fluid along the root canal and to fill the whole canal system, not only to block the apical foramina, but the dentinal tubules and accessory canals also (**ESE, 2006**).

The seal should also act as a barrier against bacteria attempting to become established

within the canal system by leakage through a deficient coronal seal (**Shipper et al. 2004**).

Obturation has always been an important principle throughout the years. A standardized technique was presented in 1961, which described preparation of a canal shape using instruments of progressively larger apical size to working length. This concept was used primarily to enable the obturation of canals using a single cone technique, as the canal taper would closely match the taper of the filling point (**Ingle, 1961**).

The importance of obturation was further advocated when guidelines were proposed for preparing a canal shape that produced an ideal three-dimensional seal radiographically, using the specific technique for obturation of warm vertical condensation (**Schilder, 1974**).

These guidelines were:

- 1) The continuously tapering preparation whereby the canal preparation progressively narrowed in an apical direction.
- 2) Maintenance of original canal anatomy in the final canal shape.
- 3) Maintenance of the position of the apical foramen in its original location.
- 4) The apical foramen should be kept as small as is practically possible.

These guidelines for cleaning and shaping were published much later (1974) than those published for obturation (1967), which questions whether the primary purpose of cleaning and shaping was being shifted towards an ideal obturation of the canal system, instead of maximal canal space debridement and disinfection.

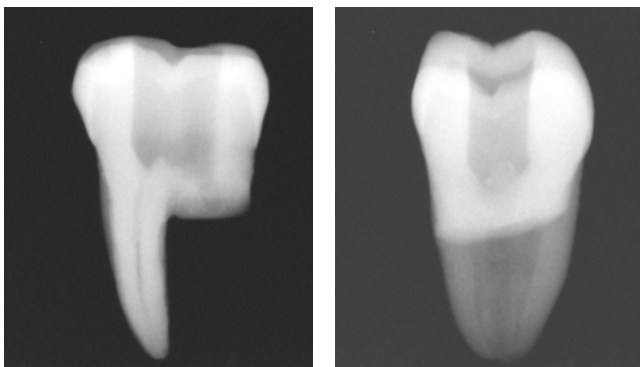
Furthermore it was proposed that canal shaping for ideal obturation would satisfy all biologic objectives for canal space debridement and disinfection. This assumption was flawed due to conflicts between biologic objectives of canal preparation, and mechanical objectives for obturation using vertical condensation of warm gutta percha (GP).

The first conflict arises from the advocacy of a canal shape maintaining the apical terminus

of the preparation at its smallest possible size. This was to reduce the risk of overfills, incomplete seals and unnecessary apical extrusion of obturation material. No scientific studies have demonstrated that a peri-apical radiolucency will develop because of the apical extrusion of an inert filling material like gutta percha (Pascon et al. 1990, Yusuf, 1982). This is in contrast to the persistence of intra-canal bacteria, which are the primary reason for treatment failure.

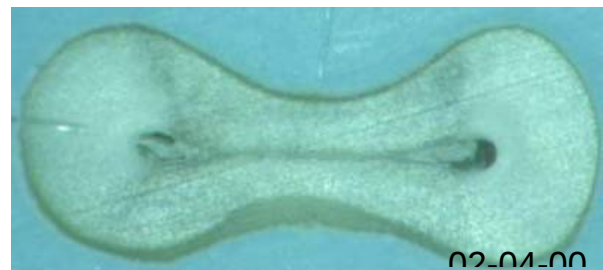
Another conflict arises from the objective requiring the canal to become progressively smaller in diameter from coronal to apex. The creation of a tapering canal is advantageous as it provides improved control when vertical forces are applied, and a greater potential for filling adaptation to the canal wall. (Schilder, 1974).

The fervor to create a defined canal taper has resulted in instrument systems being manufactured and promoted for their ability to “machine preparations with specific tapers” (Real World Endodontics, 2006). This theory has been established without consideration to canal anatomy being three-dimensional. When canal taper is reviewed from a clinical radiograph it is only being assessed in the mesio-distal dimension. The canal typically becomes progressively smaller in this dimension with an average .04 taper. When the bucco-lingual canal dimension is assessed, there is a significantly greater taper to the canal averaging .10, especially when they are oval in shape. This means that the canal remains much larger in diameter closer to the apex, and as a result a .06 taper would be insufficient to shape the canal in its proximal dimension (Wu et al. 2000).



Clinical view (left) of a mesial root from a mandibular molar with 2 separate canals. Note the small diameter and minimal taper to the canal dimensions.

Proximal view (right) demonstrating much larger canal dimensions, and greater taper, especially in the buccal canal.



Canal cross-sections from the same tooth.

Coronal canals have large buccal to lingual, and mesial to distal dimensions.

Mid-root canals demonstrate a smaller mesial to distal dimension but the buccal to lingual dimension remains similar in size to the coronal.

Apical - Mid-root canals demonstrate a further decrease in mesial to distal dimension, but the buccal to lingual dimension remains similar in size to the mid-root and coronal section.

In all three regions, the enlarged buccal to lingual dimensions will increase the difficulty of complete canal incorporation during root canal preparation.

Studies examining canal taper have shown that instrumentation techniques can create tapers in the apical 5mm of .08 taper in MB & DB canals, and .10 taper in palatal canals, without the risk of compromising canal wall thickness by over-enlargement (**Peters et al. 2003**). The use of only .08 or .10 taper instruments is not routinely endorsed to create this apical taper as these larger file tapers are at greater risk of cyclic fatigue failure in apical curvatures (**Pruett et al. 1997, Haikel et al. 1999**). Furthermore files with tapers this large usually have smaller tip diameters to maintain file flexibility. Apical enlargement would then require the use of additional files which are often not available as part of the same instrument system.

Historically, canal preparation had already been extensively examined with studies presenting the need for canal enlargement to final apical sizes greater than 40 for improved canal space debridement (**Matsumiya et al. 1960, Haga 1968**). The wisdom of these minimal preparation techniques has again been challenged more recently, as numerous studies have shown that these minimally prepared canals are less well debrided (**Mauger et al. 1998**) and disinfected, in comparison to canals prepared to satisfy cleaning and shaping objectives (**Shuping et al. 2000**). More significantly, intra-canal medicaments could not predictably ensure canals were 100% free of bacteria when canals were prepared to minimal sizes (**McGurkin et al. 2005**). This is in direct contrast with canals that have been appropriately enlarged at the first appointment (**Card et al. 2002**).

Minimal preparation techniques have also been shown to create an insufficient canal diameter for obturation instruments to penetrate within 5mm of working length (**Peters et al. 2003**). This is a critical factor for ideal obturation, since incomplete penetration will prevent adequate heat transfer for optimal adaptation of the apical filling material. A deeper penetration depth for heat carriers to within 3-5mm of working length has been proven to improve adaptation of sealing materials to the canal wall (**Smith et al. 2000**).

A two dimensional radiograph is a crude scientific method to evaluate the three dimensional seal of the canal space (**Kersten 1987**). This could be tolerated by accepting the limited evaluation techniques available historically, but with the advent of sophisticated imaging technology, such as three dimensional micro computed-tomography reconstructions (**Jung et al. 2006**), and fluid filtration leakage studies (**Pommel et al. 2003**), well recognized deficiencies in the term “ideal seal” have become further exposed. No technique has been identified in the short or long-term that is able to create a seal impervious to bacteria (**Torrabinejad et al. 1990**).

The shift of canal preparation criteria to enable the sealing of accessory canals and then subsequently review the dissolution of filling material from these canals at recall appointments challenges clinical satisfaction.





Pre-operative radiograph demonstrates no evidence of apical accessory canals.

Post-operative radiograph after canal preparation at the first appointment, the use of Calcium Hydroxide as an inter-appointment medication, and obturation using a warm vertical compaction technique and resin sealer.

Three month post treatment radiograph demonstrating initiation of resin sealer resorption or dissolution from accessory canals.

Compromising the efficiency of canal debridement or disinfection for obturation purposes does not have scientific credibility, as it has been proven repeatedly that obturation is not necessary for healing of peri-radicular pathology, providing the canal space has been suitably disinfected, (**Gutmann et al. 1992, Caliskan 1996**).

With the significant limitations in obturation based canal preparation objectives exposed, the question remained as to why modifications in preparation techniques were not accepted to improve the quality of canal preparation?

This question may be explained by the significant disadvantages afforded by stainless steel instruments. These disadvantages resulted in canal preparation becoming a compromise between ideal enlargement and the minimization of procedural shaping errors.

Stainless steel instruments demonstrated significant limitations because of their increased stiffness in larger file sizes, and this was irrespective of the file design. As a result,

instruments were only manufactured in a .02 taper. Using these files sequentially to working length created insufficient canal taper for acceptable control using warm vertical techniques for obturation. Furthermore it was accepted that enlarged apical preparation sizes were not possible due to file stiffness, considerably increasing the risk of significant transportation and deviation from the original canal path.

Step back techniques were used to prepare a canal with a suitable taper using successively larger file sizes at shorter lengths (**Clem 1969**). Establishing the apical size at a 20 or 25 meant that larger less flexible files were not required in apical curvatures, and the creation of a step-back shape could be performed using smaller sized instruments, that were more flexible and easier to control (**Walton et al. 1996**). This was in comparison to using larger and stiffer file sizes to initially increase the apical diameter, and then using even larger sized instruments to create an apical taper. In curved canals this became a more critical factor, as stiffer files increased the risk of canal transportation and produced procedural errors complicating the debridement and obturation process (**Weine et al. 1975**).

The third possible reason for minimizing apical enlargement was the ease of canal preparation to these minimal apical sizes. Maintaining a small apical size of 20 or 25 meant instrumentation was less time consuming than attempting to prepare to an apical size 35 or 40, especially with manual techniques (**Short et al. 1997**).

Speculating as to the reason for maintaining these strategies provides no currently acceptable scientific theories. The continued reliance on objectives presented 30 years ago is demonstrated by the wealth of material still written or presented based on these objectives (**Buchanan 2005, Ruddle 2002**). It also maintains the notion that Ni-Ti instruments that are now commonly used for instrumentation, demonstrate behavioral properties similar to stainless steel instruments.

INVESTIGATING ROOT CANAL PREPARATION: ADVANCES IN RESEARCH TECHNOLOGY

Scientific research has limited credibility with many clinicians. This is due to concerns with flawed experimental techniques, clinically non-reproducible methodologies, clinically irrelevant results, and a lack of statistical significance in findings. There can also be disagreement on conclusions from different studies examining the same hypothesis due to erroneous interpretations. This negative outlook has limited the impact and uptake of conclusions drawn from studies that are actually appropriately designed and performed. In addition, the results often contradict the techniques favored by contemporary lecturers resulting in greater criticism.

It is disappointing that many currently advocated techniques do not demonstrate a sound scientific basis, as there have been tremendous advances in the quality of endodontic research on root canal preparation. Techniques to evaluate the quality of canal preparation in comparison to the original canal anatomy, have been made possible using modifications of canal cross-sectioning techniques first reported in 1987 (**Bramante et al. 1987**). These techniques also allow comparison of different instrument systems within the same sample, when mandibular molars with two separate canals of similar morphology are used (**Garala et al. 2003, Ponti et al. 2002**). The use of digital imaging allows the transfer of data obtained to imaging software with numerous tools for quantitative analysis of instrument behavior and performance.

Micro CT technology has become the standard for examination of canal preparation techniques due to its accuracy and non-destructive methodology (**Peters et al. 2001**). This enables repeated evaluation of the same sample, the potential to evaluate anatomy from a three dimensional and cross-sectional perspective, and the ability to use detailed quantitative methods for analysis. The data obtained allows objective assessment of the extent of

unprepared canal spaces, extent of canal transportation, and changes in canal diameter (**Hubscher et al. 2003**). It also allows subjective evaluation of gross procedural errors such as zips and ledges (**Paque et al. 2006**).

THE INFLUENCE OF NI-TI INSTRUMENTS ON CANAL PREPARATION

The historical limitation of stainless steel instruments has been overcome by the improved flexibility of instruments manufactured from a Nickel Titanium alloy (**Walia, 1988**). Even in larger diameters and tapers, the improved flexibility facilitates the negotiation of more acute and shorter radii curvatures, which are not necessarily identifiable before treatment.



Post-treatment radiographs demonstrate the significant variations in curvature that exist, between different teeth and the root canals within teeth themselves.

Numerous studies have confirmed the unprecedented advantages that Ni-Ti instruments possess over stainless steel (**Samyn et al. 1996, Gluskin et al. 2001**). Despite these advances in instrument properties and design, the continued use of these instruments according to objectives established 30 years ago, further intensifies the debate on the purpose of canal preparation.

Since instrument flexibility no longer factors as a significant limitation to the objective of complete canal debridement, it is important to determine the remaining influences.

FACTORS INFLUENCING CANAL PREPARATION

CANAL ANATOMY

The existing root canal anatomy is now the primary challenge evident in the attempt for optimal canal debridement and disinfection.

What limitations are imposed by canal anatomy?

It has been documented since the early anatomy studies of the 1900's, that there are a multitude of accessory canals, fins, isthmuses and apical deltas (**Hess 1921**), that usually cannot be located or prepared using mechanical methods (**Versumer et al. 2002**).

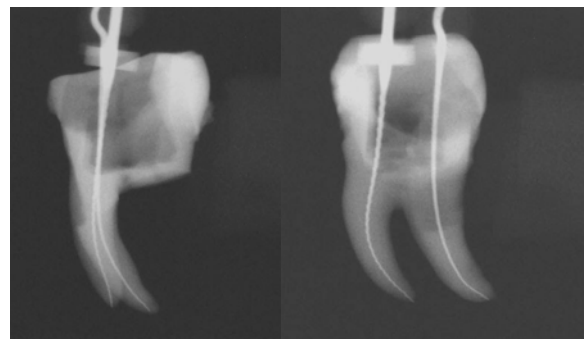
An isthmus has been defined as a narrow ribbon shaped communication between two canals containing pulp tissue (**Weller et al. 1995**), and is present 30% to 80% of the time in the apical 5mm of these canals. This can be a continuous isthmus throughout the apical 5mm, or non-continuous when it is usually located at the levels 3 to 5mm from the apex.

It must always be remembered conceptually that the root canal space is three-dimensional, and contains extensive networks and channels that can harbor bacteria or residual pulp tissue. Since these regions cannot be prepared mechanically, they will be discussed further in the section on irrigation.

Our focus during canal preparation should place emphasis on the main canal spaces that are

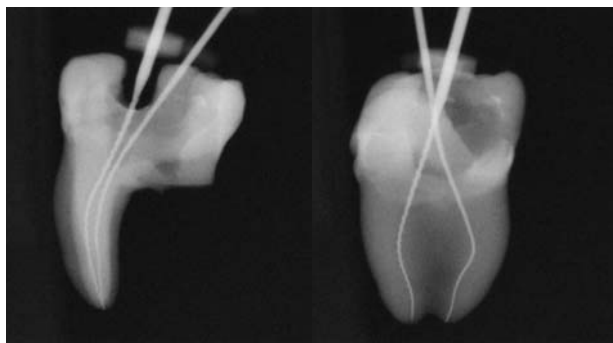
accessible for bacteria and pulpal substrate removal. Healing can be predictable if these locations are sufficiently debrided and disinfected. Lateral canals are not accessible to mechanical instrumentation and only chemical methods of debridement and disinfection exist (**Haapasalo et al. 2005**). Despite claims that lateral canals are obturated because they are completely debrided, research has shown that these canals still in fact contain significant amounts of pulpal debris, preventing the establishment of a three dimensional seal (**Venturi et al. 2003**). As a result, the achievement of canal debridement and disinfection cannot be confirmed by the radiographic presence of obturating materials in accessory canals.

The second factor related to canal anatomy is the presence of canal curvature. Curvature is inevitable in all canals with the degree and radius of curvature determining the effect it will exert on instrumentation (**Pruett et al. 1997**). This curvature is always greater from the proximal view and unfortunately this cannot be determined clinically.



Significant differences in canal curvature when the same tooth is viewed from proximal versus clinical angles.

There can also be S-shaped curves or simultaneous curves in multiple planes (Cunningham et al. 1992).



Presence of S type curvatures in mid-root when viewed from the proximal angle. This is in comparison to minimal curvature mid-root when the tooth is viewed from the clinical angle.

Curvature compromises preparation techniques by the restrictions it imparts on the instruments being used. Despite the significantly improved flexibility of Ni-Ti files compared to stainless steel, they still possess an elastic memory. This is the mechanism by which the file returns to its original shape without deformation. This elastic memory provides the restoring force for files to straighten when deformed by curvature, with the amount of this force dependant on the diameter of the file being subjected to curvature, and the degree and radius of curvature (Walia et al. 1988). This restoring force provides the mechanism for canal transportation and prevents the instrument from remaining perfectly centered for a uniform canal preparation.

The third factor is the natural size of the apical foramen and constriction, when present (Dummer et al. 1984). An exhaustive series of studies were performed to determine the diameters of these major and minor apical foramina (Green 1958). These studies found a minimum apical diameter equivalent to a size 30 file (0.3mm) for upper and lower anterior teeth, and mesial roots of lower molars. For distal roots of lower molars apical diameters were determined to be as large as 0.65mm. Another more recent study calculated the minimum and

maximum apical foramen diameters, and found 1st mandibular molars had original foramen diameters of 0.21-0.34mm. For 1st maxillary molars, maximum & minimum diameters were found to range from 0.24mm to 0.82mm (Marroquin et al. 2004).

Aging reduces the apical diameter for mesio-buccal (MB) and palatal canals of upper molars, but leaves the distobuccal (DB) apical diameter unchanged (Gani et al. 1999). It is important to distinguish between the radiographic apex, apical foramen and apical constriction as different possible endpoints of canal preparation when determining the final preparation size

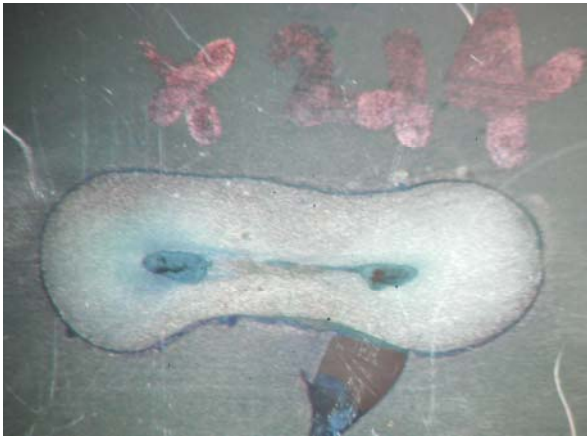
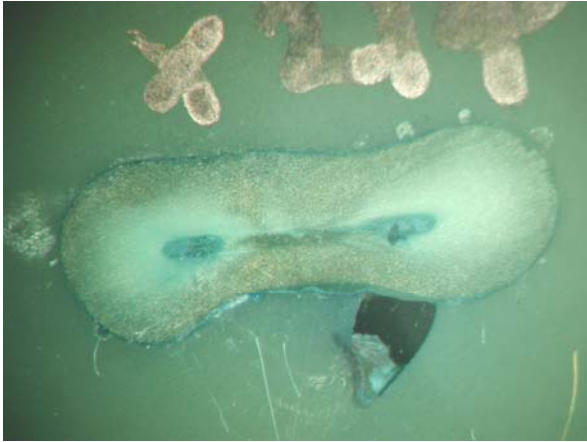
EVALUATION OF CANAL PREPARATION TECHNIQUES

Contemporary authorities on cleaning and shaping have coined the term “start with the end in mind”. If this “end in mind” should be the complete debridement and disinfection of the canal space, can it be achieved and if so, how? Why are we not predictably achieving 100% success in our canal debridement or disinfection?

From a review of the extensive endodontic literature available, assessment of canal preparation techniques and determination of preparation quality can be based on a number of criteria.

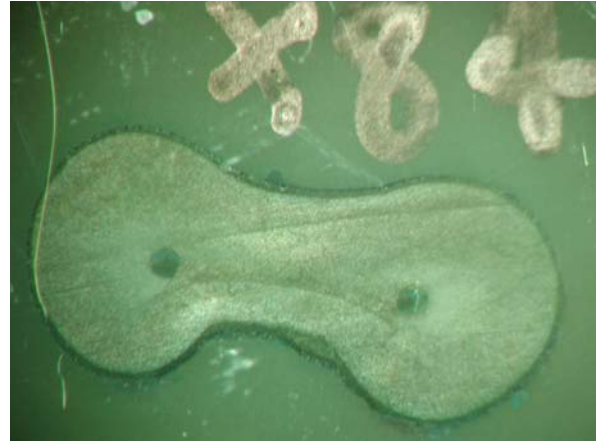
CANAL SHAPES

Despite assumptions that canals are round in cross-section their shape actually varies significantly, and they are usually irregular before preparation (Wu et al. 2000). An oval canal shape is most apparent in distal roots of lower molars, palatal roots of upper molars and teeth with roots of a narrow mesial to distal and wide buccal to lingual diameter. There are also shape transitions within the root canal itself, where fortunately the shape becomes increasingly round apically (Gani et al. 1999). The extent of initial divergence from a round shape increases the difficulty of imparting a round shape to the canal by instrumentation.

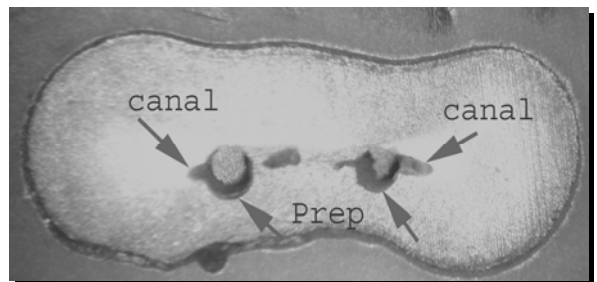


Mid-root cross sections from a mandibular molar. The canals have not changed shape significantly, despite preparation with .04 & .06 taper instrument systems, to a size 30 apically. This is due to the difficulty in complete canal incorporation during preparation due to existing canal shape and size.

In canals that are almost round, the increased flexibility of Ni-Ti instruments enables them to remain centered within the canal. As a result the final canal preparations tend to demonstrate a shape that is closer to round.



Canal cross-sections in the mid-root region of a mesial root, mandibular molar. The existing canal shape is round, which increases the likelihood of the canal shape also being round. Preparation performed using .04 & .06 taper rotary instruments to a size 30 .04 taper apically.



When the canal is oval in shape, Ni-Ti files remain centered and create a round preparation inside the original oval canal.

APICAL SHAPES

The shape of the physiological foramen on the external root surface has been classified as oval based on a difference between the wide and the narrow diameter being greater than 0.02 mm. This arbitrary criteria was established based on ISO tolerances for root canal instruments (**Wu et al. 2000**).

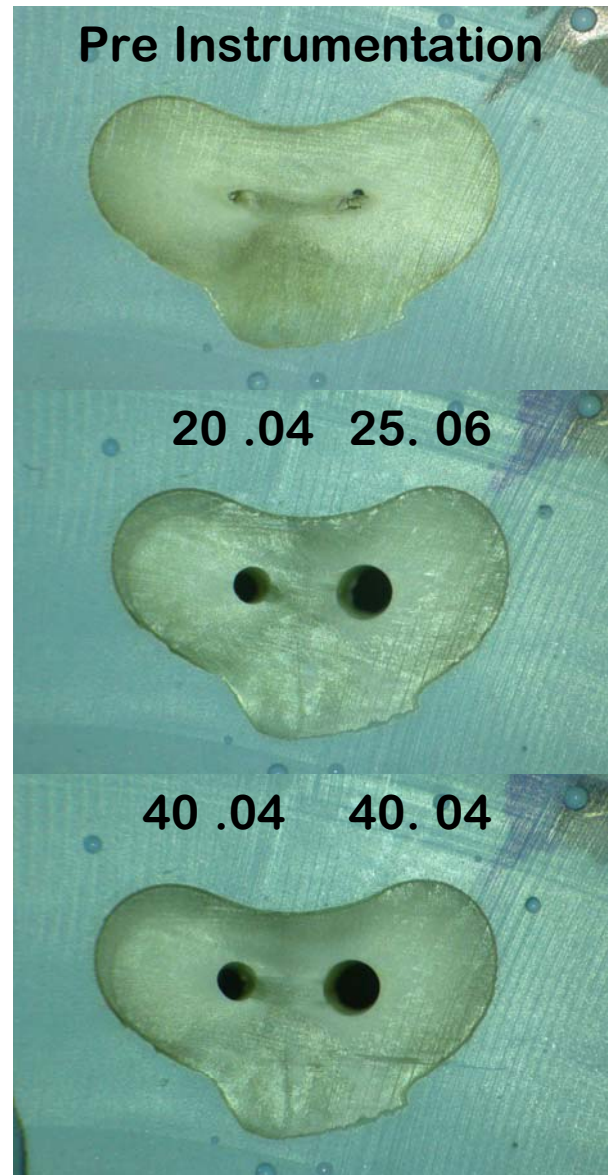
Studies have been performed examining the instrumentation size necessary to produce a round preparation 1mm from the anatomical apex. These studies confirmed that it would only be possible in MB roots of upper molars prepared to an apical size 40, DB roots to an apical size 55 and not possible in palatal canals, due to an excessively large diameter. For mesial roots of lower molars this would be an apical size 50 for mesial roots and 60 for distal roots (**Kerekes et al. 1977**).

It would be advantageous if it were possible to consistently produce a round shape, as this would closely match the cross-sectional shape of obturation materials, such as GP points or thermafil carriers (**Dentsply Tulsa, Tulsa**). This is not always possible especially in oval canals. As a result it is obvious that a condensation technique is required to adapt the obturation material to the canal wall. Using single cone systems without condensation or heating techniques, will result in a greater reliance on sealer, which is known to undergo setting shrinkage when present in large quantities (**Davalou et al. 1999**).

Stress analysis studies are also alluding to the fact that round canal preparations produce less stress concentration on roots when testing forces are applied, in comparison to oval canals (**Lertchirakarn et al. 2003**). Speculation is mounting that reducing stress concentration points on the root surface could limit the risk of root fracture (**Sathorn et al. 2005**).

CANAL INCORPORATION

If the biologic objective of preparation is to debride the canal space, the instrumentation technique being used should be able to uniformly enlarge the existing canal space into a final incorporated preparation.



Ideal canal incorporation and enlargement in the coronal third of mesial canals from mandibular molars using rotary Ni-Ti files.

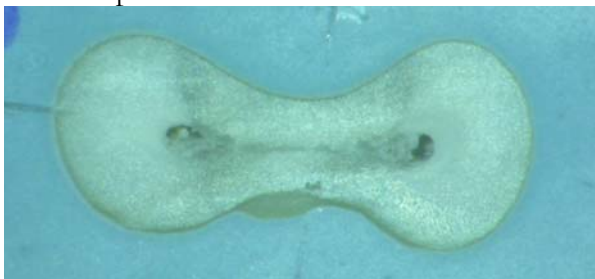
Pre-op cross-section illustrating slightly oval shaped canals (A=Left and B=Right)

Initial preparation to an apical size 20 .04 taper and preparation in canal B to an apical size 25 .06 taper. The increased size of canal B is attributed to the use of a larger instrument taper.

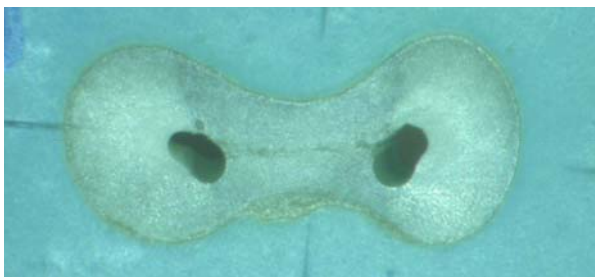
Canal enlargement to an apical size 40 .04 taper in both canals. Note there is no further enlargement of canal B in this coronal section. Canal A demonstrates some coronal enlargement but there is no transportation or excessive preparation.

Incorporation of the original canal space is highly dependent on three factors:

- 1) Existing area of canal space - It is much easier to incorporate a small existing canal space compared to a large area (**Peters et al. 2003**). The amount of unincorporated canal area decreases with coronal to apical progression, providing there is appropriate enlargement (**Rodig 2002**). This is attributed primarily to the decreasing canal area apically, and secondly the increased tendency for the canal to be round, which increases the potential for complete instrument contact of the canal perimeter.
- 2) Canal curvature – Some transportation of the existing canal space is inevitable during preparation of curved portions of the canal. In the coronal or mid-root areas this will be towards the inner aspect of the curve whereas in the apical region this will be towards the outer aspect of the curve (**Wildev et al. 1992**). This transportation will result in the existing canal space not being uniformly incorporated.



Pre-operative canal cross-section from the mid root region of a mesial root, mandibular molar with two separate canals. Canals are much larger in the horizontal or bucco-lingual dimension, than the mesial to distal dimension.



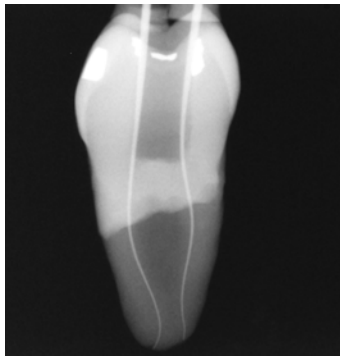
Post-operative section following preparation using rotary Ni-Ti to an apical size 40 and .04 taper in the buccal canal (left), and to an apical size 40 and .04 taper in the lingual canal (right). Note the significant transportation of the original canal outline distally towards the furcation, which has resulted in the incomplete incorporation of the canal mesially, and the resultant excessive removal of canal wall structure towards the furcation.

- 3) Canal shape - It has been confirmed that rotary instruments cannot contact and incorporate the full extent of the canal perimeter into the preparation when canals are highly irregular in cross-sectional shape. Increasing the instrument size tends to increase the size of the round preparation centrally rather than improve lateral incorporation. (**Rodig 2002**). Additional circumferential filing techniques with hand instruments in smaller sizes have been recommended to improve lateral incorporation for canals that are oval or flat in cross-section (**Wu et al. 2001**). To increase the potential for canal incorporation, brushing techniques are also advocated when using Ni-Ti instruments without radial lands (**Ruddle 2002**). There have been no scientific studies performed to confirm whether this brushing technique improves incorporation. From a safety standpoint this technique is only possible when preparing the coronal part of the canal. For the apical region this technique is not advised due to the risk of instrument failure from decreased instrument control and increased operating torque (**Blum et al. 1999**).

For an instrument system to be successful in canal incorporation, it must have instruments

possessing tapers and diameters to allow uniform enlargement of the existing canal circumference along the root length. Not all existing instrument systems reflect this feature. It has been established in clinical studies that using instruments with larger tapers and smaller tip diameters will decrease canal incorporation apically (**Peters et al. 2001**).

Apical canal incorporation is more predictable when apical sizes are enlarged providing there is no significant canal transportation (**Hulsmann et al. 2003**).



Radiograph from proximal angle shows abrupt reverse curvature in apical 2mm to 3mm.



Canal cross section with two separate canals in apical 2mm of mesial root, mandibular molar. Canals are small in dimension with a round shape.

Cross-section of canals following preparation to an apical size 30, variable taper. Uniform enlargement is evident with excellent canal incorporation.

Cross-section of canals following preparation to an apical size 55, using non-tapered files. Further uniform enlargement has occurred, with no procedural errors evident.

This becomes more critical in infected canal systems, when it is realized that apical aspects of the root canal system harbor significant amounts of bacteria often within bacterial biofilms (**Nair 2004**). The persistence of these bacteria can decrease the prognosis for clinical success.

CANAL DEBRIDEMENT

It is expected that the canal space will be completely debrided if preparation has enabled the complete incorporation of the original canal area. This occurs by the use of solutions to flush out and chemically dissolve debris (**Goldman et al. 1985**), and the direct augering of debris into the file flutes. Additional enlargement beyond the sizes required for canal incorporation is not necessary for vital canals, as canal wall dentine or tubules are not infected.

When debris is not completely removed, it is usually compacted along the surface of the canal walls by instrumentation. This debris will reduce the adaptation of sealer and gutta-percha to the canal wall (**Bowman et al. 2002**). Furthermore this increases the risk for bacteria within the debris or on the canal wall below the debris, to potentially disrupt the canal seal. Finally, if this debris is not removed it could also be compacted apically and create an apical plug preventing the complete debridement and subsequent filling of the apical region (**Iqbal et al. 2003**).

The superior cleaning ability in the coronal and middle parts of the root canal has been confirmed by studies using different rotary Ni-Ti instruments (**Gambarini et al. 2002, Hulsman et al. 2003**). It has been hypothesized that this improved cleaning efficiency is due to the flute design of Ni-Ti files (**Jeon et al. 2003, Schafer et al. 2004**).

The concern from a debridement perspective is the fate of areas of the canal that are not incorporated within the preparation. These areas are usually the lateral extensions of the canal (**Versumer et al. 2002**) and the apical regions (**Schafer et al. 2006, Wu et al. 2001**). Sodium hypochlorite (NaOCl) & EDTA solutions (Ethylene Diamine Tetra Acetic Acid) will increase the potential for debridement by tissue and debris dissolution in these areas. However this is not as predictable without instrument contact.

When it is anticipated that a canal will be oval, it appears prudent to consider the use of techniques that should provide the additional wall contact necessary for pulp tissue or bacterial disruption. This canal wall contact is predictable with the use of small diameter hand files in a circumferential filing motion following rotary Ni-Ti preparation (**Barbizam et al. 2002**). Fortunately at the level 3mm from the apex the canal becomes less oval in comparison to levels more coronal than 5mm from the apex. This results in decreased lateral recesses being evident after canal preparation (**Wu et al. 2001**).

There will be increased debris remaining in the apical third irrespective of the Ni-Ti instrument system used, when preparation techniques are employed that do not advocate apical enlargement of the canal. This finding has been attributed to the limited efficiency of Ni-Ti instruments for apical cleaning (**Schafer et al. 2004**), but is actually due to deficiencies in guidelines presented for their clinical use.

IRRIGATION

Irrigation becomes a crucial component to canal preparation, when it is accepted that areas of the

root canal system remain untouched by instruments used for debridement and concomitant shaping. It is anticipated that the use of irrigation solutions will debride and disinfect these areas during and after the instrumentation phase. For irrigants to perform these tasks efficaciously they must be delivered in sufficient quantity to the desired area, maintain exposure for a sufficient period of time (**Senia et al. 1971**), and establish dynamics for active removal of tissue, debris and bacteria from the dentinal tubules as well as the canal wall surface (**Ram 1977**). Without the use of chemically active irrigation solutions, significant material will remain in the canal space inviting treatment failure.

It was determined in 1943 that the root canal would require adequate enlargement for satisfactory irrigation (**Grossman 1943**). Numerous scientific studies evaluating irrigation efficiency and canal debridement have provided indisputable evidence that an enlarged apical canal space will result in improved irrigation dynamics (**Khademi et al. 2006**).

The improved irrigation dynamics and the mechanics of canal wall enlargement allow the removal of greater quantities of bacteria from the root canal system. It should not be overlooked that this is the ultimate goal of canal preparation in infected canals (**Sedgeley et al. 2004**).

A study was recently performed where the depth and diameter of needle penetration was controlled for differing apical preparation sizes. With apical sizes smaller than a size 35, no irrigant movement was observed apically, irrespective of the depth of needle penetration. It was shown that canals require preparation to an apical size 50 for irrigant flow at the apex when a 27 gauge needle is used to a depth 6mm short of working length. This would appear to closely approximate the needle penetration depths possible clinically in curved canals. With a final apical size of 35, a 27 gauge needle would need to penetrate to within 3mm of working length for irrigant flow (**Hsieh et al. 2007**). Clinicians should be

wary of allowing conventional irrigation systems to penetrate this close to working length, due to the risk of solution extrusion into the peri-apical tissues (**Becker et al. 1974**). The safety of more recent designs of pressure based irrigation systems such as Rinsendo (**AirTechniques.com**) has yet to be established.

Unless cuspid canals are enlarged to at least a size 46 .04 taper apically, irrigation efficacy will be compromised when curvature greater than 25 degrees is present. This is despite needle penetration occurring to within 1mm of working length (**Nguy et al. 2006**).

It has also been observed by other researchers, that an apical size 40 with a .04 or .06 taper is necessary for superior debris removal in an anterior or premolar canal. Another study determined that a final apical taper of .10, and an apical diameter of at least a size 20 would be necessary in anterior or premolar teeth, to increase canal volume sufficiently for irrigant movement (**Albrecht et al. 2004**).

In conclusion, irrigation solutions are unable to perform their required tasks without appropriate canal space enlargement. Increasing the duration of solution activity cannot compensate for inadequate apical enlargement (**McGurkin et al. 2005**). If enlarging apical preparations reduces remaining dentinal debris then it can be expected that bacterial loads will also be reduced (**Usman et al. 2004**).

ROOT CANAL INFECTIONS

CAN ALL BACTERIA BE REMOVED FROM AN INFECTED ROOT CANAL SYSTEM?

The answer using existing techniques and principles is quite clearly no! There are always ramifications and isthmuses that are inaccessible to instrumentation that will prevent complete canal disinfection (**Nair et al. 2005**). If the canal cannot be completely disinfected, the goal for canal disinfection should be re-evaluated. Some authors have conceived the term “critical mass” or “remaining bacterial threshold”. This is the term given to substantially reducing the

bacterial load to a negligible level or a level that cannot be detected by sampling techniques. This will remove the etiology for persistent periapical inflammation and enable the periapical tissues to enter a reparative or regenerative phase.

CAN INSTRUMENTATION USING NI-TI INSTRUMENTS IMPROVE CANAL DISINFECTION?

Historically, authors using histological and sampling techniques have demonstrated that increasing the apical diameter of preparations even with stainless steel instruments improved the removal of bacteria from canals (**Orstavik et al. 1991**). There was no significant difference between stainless steel and Ni-Ti instruments in bacterial load reduction, when the apical diameters were identical (**Dalton et al. 1998**). Reduction in bacterial load was attributed to canal enlargement rather than the specific type of instrument used. However Ni-Ti instruments will enable larger apical sizes to be achieved more efficiently and with minimized risk of procedural errors.

The theory that enlarged apical diameters will enable improved irrigation efficacy, was reinforced by significant reductions in bacterial loads when NaOCl was used for irrigation during canal preparation (**Shuping et al. 2000**). These studies were based on sampling techniques, which only allow sampling from the main canal. It will also only detect bacteria that are sensitive to the sampling and culturing method.

Bioluminescence appears to be a promising tool for the sequential evaluation of bacteria remaining following canal preparation, due to its non-destructive technology, which allows progressive testing on the same sample. It also measures bacteria remaining in the canal versus bacteria that can be detected by sampling. This allows the detection of bacteria present in areas such as isthmuses and fins, which are inaccessible to instrumentation or sampling techniques. One study on human cuspids using this method, showed 20% versus 10% of the original bacterial count

remained following apical preparation to a size 36 compared to a size 60. However, only saline was used as an irrigant (**Sedgeley et al. 2004**).

A similar study on cuspids was performed using a sampling technique for bacterial detection. This found canals prepared to an apical size 60 contained no bacteria after preparation using 1% NaOCl for irrigation (**Card et al. 2002**).

Attention has also been directed to the presence of microorganisms in dentinal tubules. Bacteria can contaminate tubules 200-220um from the canal wall equivalent to file sizes 20 to 25 (**Siqueira et al. 2002, Love et al. 2002**). This equates to a requirement of canal enlargement by at least 4 file sizes. Studies using a final flush of EDTA and NaOCl solutions have only been found to remove bacteria from one third of the overall length of contaminated tubules (**Berruti et al. 1997**). Apical enlargement to a size 50 or 60 versus a final apical size of 35 to 45 has been shown to improve bacterial removal from tubules by radioactive bacterial labeling studies (**Rollinson et al. 2002**).

Fortunately it has recently been shown that many tubules, especially those in the apical region, are occluded by intra-tubular calcification, which develop from age 30 onwards. This tubular occlusion will prevent the active movement of bacteria or solutions within them. (**Paque et al. 2006**). In these instances bacteria could only be present in the main canal and in accessory canals. This reinforces the theory that apical instrumentation and disinfection should primarily focus on the main canal spaces, where significant numbers of bacteria can reside.

Other areas where the canal cannot be adequately debrided using instrumentation and irrigation techniques, are now becoming the primary focus of concern for studies evaluating canal debridement techniques. Canals such as MB and ML roots of lower molars that demonstrate inter canal communications, will invariably possess an isthmus of varying length and patency (**Weller et al. 1995**). Debridement studies have shown that when an isthmus is present between canals in lower molars, hand

and rotary instrumentation of the main canals and using 6% NaOCl resulted in low isthmus cleanliness values of 15-38% (**Gutarts et al. 2005**). Isthmus cleanliness (73-95%) was significantly improved, when an ultrasonic needle with continuous NaOCl flow was used after canal shaping. This was achieved even though the duration of activation was reduced from 3mins to 1min (**Gutarts et al. 2005**).

From bacterial sampling studies in lower molars, it was found that 93% of mesial roots are bacteria free by preparing the apical diameter to a size 45 to 50, once it has been confirmed that there is no communication between the two roots. Where there is communication in the form of isthmuses or anastomoses these mesial roots can only be rendered free of bacteria in 83% of cases (**Card et al. 2002**). Light microscopy and transmission electron microscopy studies of mandibular molars have visually confirmed the presence of bacteria remaining inside these isthmuses in 91% of samples, following chemo-mechanical preparation using manual or rotary techniques, but without ultrasonics. It was also determined that bacteria persisted inside accessory canals in 63% of cases (**Nair et al. 2005**).

The impact of retained bacteria in these areas on the success rate for endodontic treatment should be evaluated. It should be recognized that not all teeth can be rendered free of bacteria by canal preparation and irrigation alone, and the merits of two-visit treatment with an inter-appointment medication should be considered.

It is indisputable that an enlarged preparation will result in a canal with less remaining debris and bacteria. All techniques to accomplish this without jeopardizing the root canal integrity should be incorporated into our regime for instrumentation.

CAN THE USE OF NI-TI INSTRUMENTS DECREASE THE RISK OF A FLARE UP OCCURRING?

Bacterial extrusion during canal preparation creates a periapical immunological response,

and is purported to be the major etiological factor in the establishment of an inter-appointment flare up (**Siqueira 2003**).

A significant advantage of rotary instrumentation is the reduced debris extrusion that occurs, irrespective of whether the endpoint of preparation is the apical foramen or constriction. This is attributed primarily to rotary instruments creating less pressure for the apical movement of debris, compared to the use of hand files in a push/pull filing motion, which creates significantly more apical pressure (**Reddy et al. 1998**).

The theory that improved file design enables improved debris collection for removal at the canal orifice has yet to be confirmed, since debris extrusion was similar irrespective of different Ni-Ti file designs (**Ferranz et al. 2005**).

The use of patency files does not allow live bacterial contamination of the apical tissues providing there is hypochlorite within the canals (**Izu et al. 2004**). However this does not prevent an inflammatory or immunologic response, since dead bacteria and the by-products of their breakdown can also stimulate the body's defense mechanisms (**Seltzer et al. 1985**).

REVISED GUIDELINES FOR CANAL INSTRUMENTATION

PREPARATION TECHNIQUES

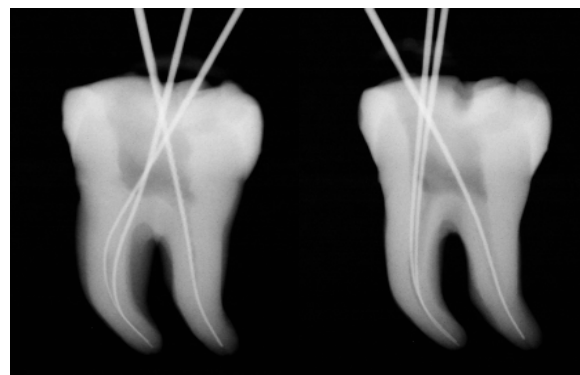
In depth preparation techniques are beyond the scope of this chapter but are presented in precise detail by Dr. Mc Spadden's chapter "Mastering Endodontic Instrumentation".

CORONAL PREPARATION

Crown down preparation describes the initiation of instrumentation by coronal enlargement, using instruments of progressively smaller diameter or taper to deeper penetration depths within the canal. The perceived biological advantage to crown down preparation is the removal of debris and reduction in bacterial loads by early enlargement of the canal space (**Goerig et al. 1982**). This reduces transportation of debris apically and potential

extrusion of this debris, when instruments are used to negotiate the apical region. It also decreases the risk of this debris being compacted and potentially blocking the narrower diameters of the canal present apically.

Coronal flaring using Gates Glidden burs or by Ni-Ti orifice openers, will also remove the coronal interferences, and in turn provide the operator with improved tactile sensation of apical file binding. It will also eliminate or significantly reduce the effect that the initial curvature will exert on files used to prepare the mid-root and apical regions. This initial curvature is present in many teeth, especially upper and lower anteriors, and mandibular molars.



Insertion of 3 size 15 K-files to radiographic working length prior to coronal flaring, to demonstrate the coronal curvature that files must negotiate before also negotiating the mid-root curvature (left)

Coronal flaring of the canal by a crown down technique to remove coronal interferences. This removes coronal curvature and provides straight-line access to the mid-root curvature (right).

The risk of excessive enlargement in the coronal third becomes a factor when oversized instruments are used inappropriately or the roots are very thin. Caution should be used even when using anti-curvature techniques for instrumentation, as instruments still tend to be deflected towards

the furcation by the initial curvature (**Bergmans et al. 2003**). Even when non-radial landed instruments were used judiciously, there was still some transportation evident in comparison to instruments with radial lands (**Bergmans et al. 2003**). This was attributed to the increased instrument diameter coronally and the lack of radial lands for greater control of instrument centering. This transportation does not become exaggerated further by progressive canal preparation even when the final apical size is enlarged.

CAN IDEAL APICAL SIZES BE DETERMINED CLINICALLY?

Apical gauging has been presented as a basis for determining final apical size following initial canal preparation (**Ruddle 2002**). It is defined as the use of instruments with a taper smaller than the taper of the prepared canal, to assess instrument binding at the final working length. When a file encounters resistance to further apical progression, it is assumed that this file is circumferentially engaging the canal wall. This instrument size is then used to finalize the apical diameter. For advocates of the apical preparation being kept as small as possible, this would be the final size to which the apical terminus is prepared (**Buchanan 2005**). For advocates of apical enlargement, this would be the size from which enlargement would occur. The technique of apical gauging has been shown to have very significant limitations in determining the apical size, as the tactile resistance that the clinician encounters is being obtained from only one side of the canal wall in 75% of cases, and from no wall contact in the other 25% of cases. This is in contrast to the perceived engagement of the entire canal periphery (**Wu et al. 2002**).

Secondly, if gauging is attempted before coronal enlargement, the binding sensation may not be from the apex, but from the file binding in coronal or mid-root regions. This is especially true in canals that demonstrate significant curvature (**Leeb et al. 1983**). Finally, even with the use of files with a smaller taper, some contact with the canal wall is inevitable in the

presence of curvature, which will also affect the tactile feedback from the apical terminus.

If it is still envisaged that the original canal is incorporated at this size, canal enlargement should be considered by a minimum of 3 to 4 file sizes greater than this size. This is in an attempt to ensure adequate removal of infected pre-dentine and dentinal tubules from infected teeth, and pulp tissue remnants and debris in vital teeth (**Wu et al. 2002**). This will minimize the reliance on irrigation regimes, which may not predictably provide a satisfactory volume of irrigant for tissue dissolution, or be present for enough time inside dentinal tubules for efficacious disinfection (**Safavi et al. 1990, Buck et al. 1999**).

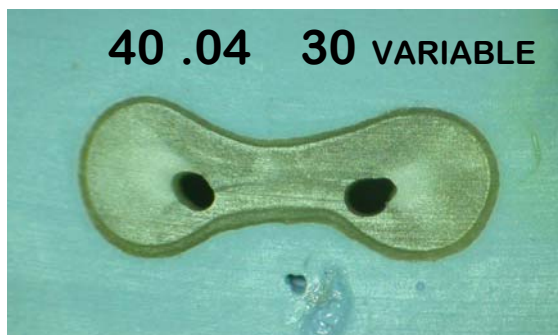
The final apical size for predictable debridement and disinfection can be more accurately determined from many of the studies discussed in the preceding sections. In infected cases these studies advocate minimum apical preparations to a size 60 in cuspids and single rooted premolar teeth, size 45 to 50 in mesial roots of lower molars where there are two separate canals, and to a size 55 to 57.5 for mesial canals demonstrating a communication (**Card et al. 2002**). It is important to note that these final apical sizes were not achieved just using instruments of greater taper. Molar canals were prepared to a maximum apical diameter of 46.5 and straight premolar canals to a size 60 using Profile Series 29 instruments, after which Lightspeed instruments were used. These instruments are beneficial from a sizing perspective because they only incorporate a single cutting blade behind the passive tip (**Lightspeed, Lightspeed Inc., San Antonio, TX**). This has been shown to minimize the risk of canal enlargement outside the apical region. Rotary Ni-Ti files of .02 taper have also been used in other studies for apical preparation with no reported perforations or excessive canal enlargement that could compromise root integrity (**Rollinson et al. 2002**).

CAN CANALS BECOME EXCESSIVELY ENLARGED TO THE EXTENT WHERE THE WALL THICKNESS BECOMES COMPROMISED?

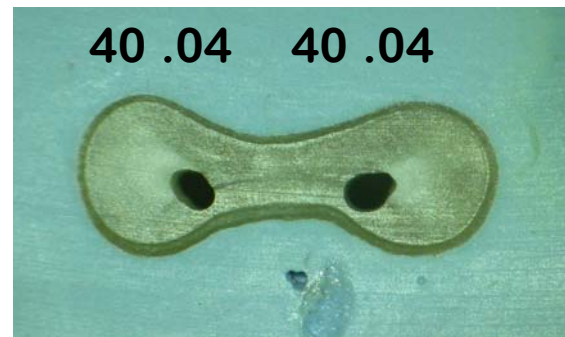
Studies that have been performed to examine the canal wall thickness before and after instrumentation have consistently concluded that the existing canal wall thickness is the most significant factor for determining the canal wall thickness that will remain following preparation with Ni-Ti instruments (**Montgomery 1985**). The amount of dentine removal was not shown to reduce the remaining tooth structure to less than 50% of the original wall thickness and always left greater than 1mm of remaining dentin even in the smallest dimension (**Garala et al. 2003**). Again these results are based on the excellent centering properties of Ni-Ti instruments, which decreases the amount of canal transportation that can compromise canal wall thickness. Even when there has been initial canal transportation by previous instruments the subsequent use of larger diameter instruments does not further compromise the remaining canal wall structure.



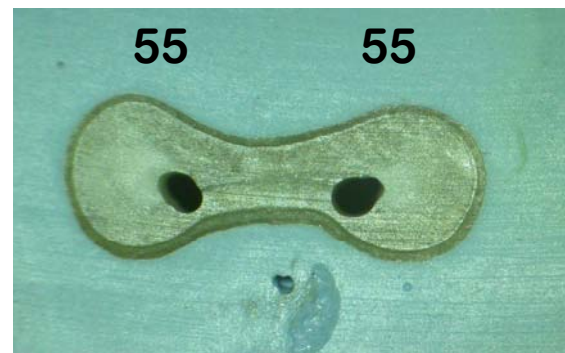
Mid-root cross-section from a mandibular molar with two separate mesial canals that are small and approximate a round shape.



attributed to the section being at the height of the mid-root curvature where transportation is inevitable.



Additional enlargement to an apical size 40 .04 taper does not increase transportation, or result in further unnecessary removal of canal wall structure.



Further enlargement to an apical size 55 does not increase mid-root transportation.

If the canal is not being significantly transported with files of larger tip diameters and smaller taper, what other possible negative consequences are there anatomically when attempting to increase apical preparation sizes?

Obviously inappropriate instrument diameter and taper selection will increase the risk of unnecessarily compromising canal wall structure. The clinician is limited to just radiographs when attempting to determine the canal wall thickness. However studies examining canal taper have shown that instrumentation techniques can create tapers of .08 taper in MB & DB canals, and .10 in palatal canals, without concerns of over-

enlargement compromising canal wall thickness (Peters et al. 2003).

DOES IT MATTER WHICH INSTRUMENT SYSTEM IS USED?

Despite the extensive marketing strategies used to promote Ni-Ti instruments, no conclusion can be drawn from the scientific literature that the design features of any instrument system will provide increased success in canal space debridement or disinfection. Instrument selection should therefore be based on the ability to safely prepare the canals rather than for perceived benefits in canal cleanliness.

Any improvement in canal preparation should be attributed to the appropriate preparation sizes that can be attained using these instruments, and this is dependent on the instrument sizes manufactured and their protocol of use.

There has been only one outcome study performed to determine endodontic success rates when different Ni-Ti instruments are used for preparation (Peters et al. 2004). This study determined that there was no difference in success rates based on canal preparation protocols or the types of Ni-Ti file used. The ability to demonstrate a significant difference between techniques that advocate minimal or enlarged preparations is difficult, because as mentioned previously endodontic success rates are not solely related to canal debridement and disinfection. It also becomes challenging to demonstrate a statistical significance in scientific studies, due to the high clinical success rates already evident for endodontic treatment, and the need for very large sample sizes to demonstrate differences.

CONCLUSIONS

A wealth of evidence based information on all aspects of root canal preparation has been critically reviewed in an attempt to expose the clinical relevance of innovative and technologically exemplary scientific research. This information serves to remind us that there are unbiased scientific principles which can be incorporated in our clinical protocol, to provide a biologic foundation for root canal preparation. The application of these principles and the re-alignment of our objectives back towards canal preparation should enable us to provide more predictable cleaning and shaping strategies. The importance of this most critical aspect of endodontic treatment cannot be overstressed, and there will always remain unpredictability to our treatment without the realization of these biologic goals.

With the clear establishment of biologic and mechanical objectives for canal preparation, and the techniques presented to predictably achieve these objectives, the method of incorporating these techniques using safe and efficient protocols for Ni-Ti instruments will now be presented in the chapter “Mastering Endodontic Instrumentation”.

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